GEOLOGY AND MINERALIZATION OF THE LUSHS BIGHT GROUP

B.F. Kean, D.T.W. Evans and G.A. Jenner

Report 95-2

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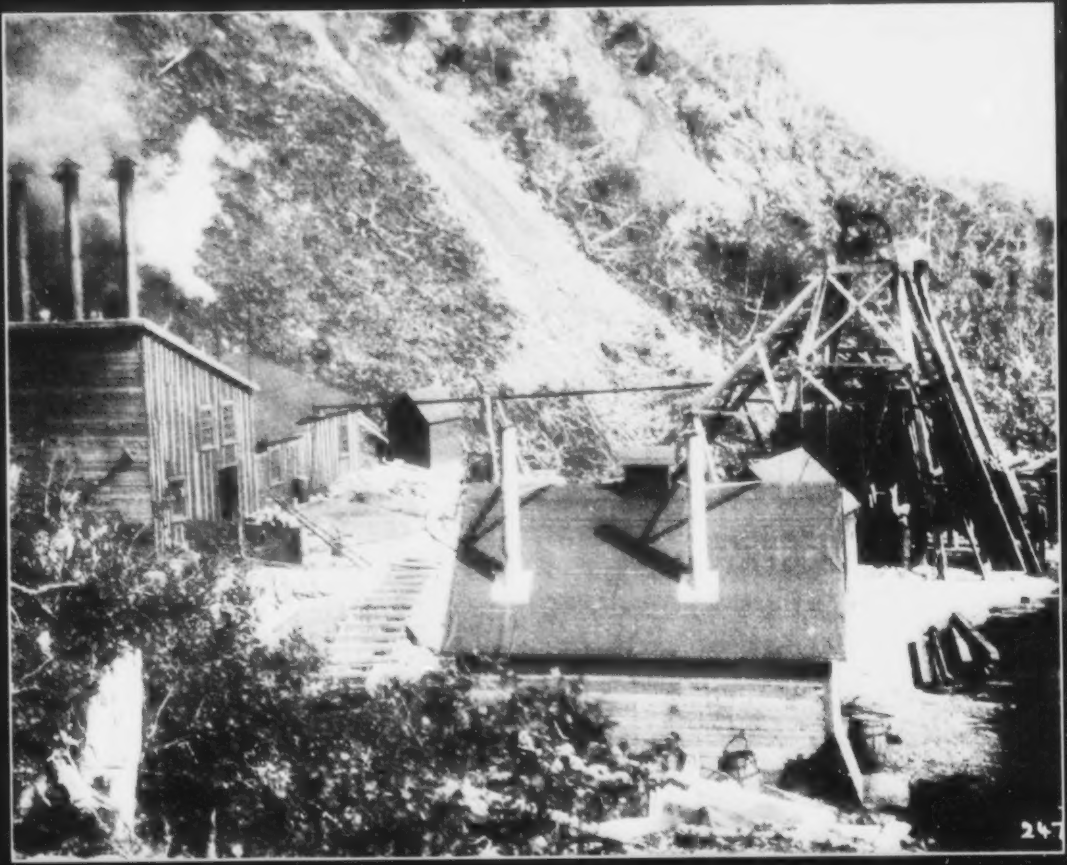

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COVER

The Little Bay Mine, ca. 1890. The picture, possibly of the Seary Shaft, shows the stream-driven hoist in operation. The Little Bay Mines operated from 1874 to 1894 and produced an estimated 545 000 tonnes, grading 2.5 percent Cu. (Photo courtesy of Provincial Archives of Newfoundland and Labrador.)

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CONTENTS

Page

- ABSTRACT ... xix
- INTRODUCTION ... 1
  - LOCATION AND ACCESS ... 1
  - PREVIOUS WORK ... 1
  - PRESENT INVESTIGATION ... 3
  - PHYSIOGRAPHY ... 3
  - REGIONAL SETTING ... 7
- GENERAL GEOLOGY ... 8
  - INTRODUCTION ... 8
  - LUSHS BIGHT GROUP ... 9
    - Definition and Division ... 9
    - Ultramafic Rocks ... 9
      - Distribution ... 9
      - Description ... 10
      - Petrography ... 10
      - Structure and Metamorphism ... 10
      - Contact Relationships ... 10
    - Sheeted Dykes ... 10
      - Distribution ... 10
      - Description ... 11
      - Petrography ... 11
      - Structure and Metamorphism ... 11
      - Contact Relationships ... 12
    - Volcanic Rocks ... 12
      - Distribution and Division ... 12
      - Description ... 12
      - Petrography ... 16
      - Structure and Metamorphism ... 20
      - Contact Relationships ... 22
  - OVERLYING SEQUENCES ... 24
  - INTRUSIVE ROCKS ... 24
    - Introduction ... 24
      - Brighton Gabbro Complex ... 24
        - Definition and Distribution ... 24
        - Description ... 25
        - Petrography ... 26
        - Structure and Metamorphism ... 27
        - Contact Relationships and Age ... 27
      - Colchester Pluton ... 27
        - Definition and Distribution ... 27
        - Description ... 27
          - Marginal Phase ... 27
          - Transitional Phase ... 27
          - Central Phase ... 28
        - Petrography ... 28
          - Marginal Phase ... 28
          - Transitional Phase ... 28
          - Central Phase ... 28
        - Structure and Metamorphism ... 28
        - Contact Relationships and Age ... 28
      - Cooper's Cove Pluton ... 28

Page

        Definition and Distribution 28
        Description 29
            Marginal Phase 29
            Central Phase 29
        Petrography 29
            Marginal Phase 29
            Central Phase 29
        Structure and Metamorphism 29
        Contact Relationships and Age 29
    Wellman's Cove Pluton 29
        Definition and Distribution 29
        Description 30
        Petrography 30
        Structure and Metamorphism 30
        Contact Relationships and Age 30
    Bob Head Pluton 30
        Definition and Distribution 30
        Description 30
        Petrography 31
        Structure and Metamorphism 31
        Contact Relationships and Age 31
    Younger Dykes 31

STRUCTURE AND METAMORPHISM 32
  STRUCTURE 32
  METAMORPHISM 34

GEOCHEMISTRY 36
  INTRODUCTION 36
  ALTERATION 36
    Discussion 36
    Methodology 39
      Major Elements 40
      Low-Field-Strength Elements (LFSE) 41
      High-Field-Strength Elements (HFSE) 41
      Rare-Earth Elements (REE) 41
      Transition Elements (TE) 44
  GEOCHEMICAL GROUPS 44
  ROCK CLASSIFICATION 47
  INTERPRETATION OF VARIATION DIAGRAMS 47
    Low-Field-Strength Elements (LFSE) 47
    Transition Elements 48
    Th and HFSE 48
    REE 50
      Lavas 52
      Dykes 56
      Felsic Volcanic Rocks 58
    Sm—Nd Isotopes 58
    Summary 58
  SPATIAL RELATIONSHIPS OF THE GEOCHEMICAL GROUPS 61
  COLCHESTER AND COOPER'S COVE PLUTONS 63

ECONOMIC GEOLOGY 65
  INTRODUCTION 65
  CHLORITE-SCHIST ZONES 65

Page

MINERAL DEPOSITS 70
  Mineral Occurrences Hosted by Sheeted Diabase Dykes 71
    Indian Head (Keatons Adit) (NTS 2E/12 Cu026) 72
      Location 72
      History of Development 72
      Local Geology and Mineralization 72
    Indian Beach (NTS 2E/12 Cu027) 73
      Location 73
      History of Development 73
      Local Geology and Mineralization 73
  Mineralization in Mafic Volcanic Rocks 73
    Miles Cove Mine (NTS 2E/12 Cu012) 78
      Location 78
      History of Development and Production 78
      Local Geology and Mineralization 80
    Jerrys Harbour (NTS 2E/12 Cu015) 81
      Location 81
      History of Development 82
      Local Geology and Mineralization 82
    North Paddock's Bight (NTS 2E/12 Cu016) 82
      Location 82
      History of Development 82
      Local Geology and Mineralization 82
    Delaney Shaft (NTS 2E/12 Cu029) 83
      Location 83
      History of Development 83
      Local Geology and Mineralization 83
    Little Bay Mine (NTS 2E/12 Cu030) 84
      Location 84
      History of Development and Production 84
      Local Geology and Mineralization 87
    Sleepy Hollow (North Zone) (NTS 2E/12 Cu031 and Au003) 89
      Location 89
      History of Development and Production 89
      Local Geology and Mineralization 90
    Shoal Arm and Little Bay Head (NTS 2E/12 Cu032 and Cu033) 91
      Location 91
      History of Development 91
      Local Geology and Mineralization 92
    Whalesback Mine (NTS 12H/9 Cu001) 92
      Location 92
      History of Development and Production 92
      Local Geology and Mineralization 92
    Little Deer Mine (NTS 12H/9 Cu002) 96
      Location 96
      History of Development and Production 96
      Local Geology and Mineralization 96
    Rendell-Jackman Prospect (NTS 12H/9 Cu003) 98
      Location 98
      History of Development and Production 98
      Local Geology and Mineralization 99
    McNeily (NTS 12H/9 Cu004) 100
      Location 100
      History of Development and Production 101
      Local Geology and Mineralization 101
    Colchester—Main Zone (NTS 12H/9 Cu005) and West Colchester (NTS 12H/9 Cu006) 103

Page

Location 103
History of Development and Production 103
Local Geology and Mineralization 104
Old English (NTS 12H/9 Cu007) 105
Location 105
History of Development and Production 106
Local Geology and Mineralization 106
Swatridge (NTS 12H/9 Cu008) 106
Location 106
History of Development and Production 107
Local Geology and Mineralization 107
Sterling Mine (NTS 12H/9 Cu009) 107
Location 107
History of Development and Production 107
Local Geology and Mineralization 107
Twin Pond Prospect (NTS 12H/9 Cu010) 109
Location 109
History of Development and Production 109
Local Geology and Mineralization 109
Sullivan Pond (NTS 12H/9 Cu011) 110
Location 110
History of Development and Production 110
Local Geology and Mineralization 111
Lady Pond Mine (NTS 12H/9 Cu013) 111
Location 111
History of Development and Production 111
Local Geology and Mineralization 112
Timber Pond (NTS 12H/9 Zn002 and Au003) 114
Location 114
History of Development 115
Local Geology and Mineralization 115
Mineralization in Sediments Overlying the Lushs Bight Group 118
Nickey's Nose—Rushy Pond—Rushy Pond Head Prospects (NTS 2E/12 Pyr013, Pyr014, Pyr015) 118
Location 118
History of Development and Production 118
Local Geology and Mineralization 118
Yogi Pond (NTS 12H/9 Pyr001) 119
Location 119
History of Development 119
Local Geology and Mineralization 119
Vein-Hosted Mineralization 119
Hearn Gold Prospect (NTS 2E/12 Au001) 119
Location 119
History of Development 119
Local Geology and Mineralization 120
Mine Brook (NTS 12H/9 Au001) 122
Location 122
History of Development and Production 122
Local Geology and Mineralization 123
The Hammer Down Deposit (NTS 12H/9 Au009) 123
Location 123
History of Development 123
Local Geology and Mineralization 123
Silverdale (Bear Cove) (NTS 2E/12 Pb001) 126
Location 126

Page

History of Development 126
Local Geology and Mineralization 127

SUMMARY AND CONCLUSIONS 129

ACKNOWLEDGMENTS 130

REFERENCES 130

APPENDIX 1—List of reports on the Lushs Bight Group 142

APPENDIX 2—Complete geochemical dataset for the Lushs Bight Group, overlying sequences and intrusive rocks 162

Table 2-1. Lushs Bight Group lavas 162
Table 2-2. Lushs Bight Group diabase and fine-grained gabbro 171
Table 2-3. Cutwell, Catchers Pond and Western Arm (WAG) Groups 190
Table 2-4. Cooper's Cove and Colchester plutons 194
Table 2-5. Geochemistry of intrusive rocks (mostly fine-grained mafic) that have not been assigned to any group 196

APPENDIX 3—Analytical statistics 200

FIGURES

Page

Figure 1: Simplified geological map of Newfoundland with tectonostratigraphic subdivisions 2

Figure 2: Geological map of the Springdale Peninsula showing distribution of the major rock types in the Lushs Bight Group. Stippled areas consist of variolitic pillow basalt. (Ultramafic rocks are too small to be shown on this map) 4

Figure 3: Classification of chlorites of the Lushs Bight Group (after Hey, 1954) 18

Figure 4: AFM plot of chlorite compositions: ■—mineralized chlorite schist; ●—unmineralized chlorite schist; X—greenschist basalt 20

Figure 5: Regional facing direction of rocks in the Springdale Peninsula area 33

Figure 6: Alteration-mineral assemblages and proportions as predicted by varying seawater to rock ratios at 300°C. (Based on experimental data from basalt-seawater reactions at 300°C and 500 to 600 bars; Mottl, 1983) 35

Figure 7: Composition of chlorites from seafloor greenstones including typical metabasalt and chlorite-quartz metabasalt (field A) compared with chlorite composition from chlorite—quartz—sulphide-rich breccias (field B) in an upwelling zone (Mottl, 1983). Field C represents the range of composition from Mg-rich host metabasalt to Fe-rich mineralized chlorite schist in the Whalesback, Little Bay, and Colchester areas (after Bachinski, 1972). Field D includes the Little Deer, Rendell-Jackman, Lady Pond, McNeily, Stirling mineralized sequences. Field E is unmineralized chlorite schist and host metabasalt (this study) 35

Figure 8: Model for the structure and evolution of hydrothermal systems at the axis of a mid-ocean ridge (after Mottl, 1983). The diagram is a schematic cross section parallel to the axis. Downwelling indicated by arrows occurs partially in but mainly outside the plane of the diagram. The suggested evolutionary sequence is from shallow to deep circulation (B) as the former magma chamber is penetrated, and from warm to hot vents (A) as the upflow zone is isolated by sulphide deposition. Hot vents may occur near the 300°C isotherm. Rapid shallow circulation keeps the upper crust cold. The sharp drop in temperature near the top of the upflow is due to mixing only; the deeper cooling is adiabatic 36

Figure 9: Comparisons of alteration effects on K_2O, Rb, Zr and TiO_2 45

Figure 10: TiO_2 vs Mg# diagram showing the major geochemical groups in the Lushs Bight Group (A—lavas, B—dykes). Non-arc/arc division line based on complete trace-element evaluations for the Lushs Bight Group and is not intended for use with other rocks. Dotted field boundaries in B indicate groups defined for the lavas; additional groups present only for the dykes are shown by solid lines (e.g., LOTI-FH, LOTI-F, CAB). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure 46

Figure 11: Primitive mantle normalized plot of selected (immobile) elements for modern boninites and Lushs Bight Group boninites. Data for modern boninites from Jenner (1981, 1982). Normalizing values after Hofmann (1988) 46

Page

Figure 12: AFM ternary (cation percent; Jensen, 1976) plot for boninites of the Lushs Bight Group (solid diamonds) and modern boninites (crosses). Data for modern boninites from Jenner (1981, 1982). HFT = high Fe tholeiite; HMT = high Mg tholeiite; BK = basaltic komatiite; PK = peridotitic komatiite; T = tholeiite; C = calc-alkaline. (A = andesite, B = basalt, D = dacite, R = rhyolite) 46

Figure 13: AFM ternary (cation percent; Jensen, 1976) plot for selected non-boninitic Lushs Bight Group dykes and lavas (A—lavas, B—dykes). Data for modern boninites from Jenner (1981, 1982). HFT = high Fe tholeiite; HMT = high Mg tholeiite; BK = basaltic komatiite; PK = peridotitic komatiite; T = tholeiite; C = calc-alkaline. (A = andesite, B = basalt, D = dacite, R = rhyolite). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS 47

Figure 14: Modified FeO* vs FeO*/MgO plot (Miyashiro, 1974) for selected non-boninitic Lushs Bight Group dykes and lavas (A—lavas, B—dykes). TH—tholeiitic trend; CA—calk-alkalic trend. ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS 48

Figure 15: MnO—TiO_2—P_2O_5 discriminant plot (after Mullen, 1983) for non-boninitic Lushs Bight Group lavas and dykes (A—lavas, B—dykes). OIT—ocean-island tholeiites; OIA—ocean-island basalts; MORB—mid-ocean ridge tholeiites; IAT—island-arc tholeiites; CAB—calc-alkalic basalts. (Note: Plots were screened for samples with silica content between 45 and 54 percent.) ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS 49

Figure 16: Zr/TiO_2 vs Nb/Y diagram (Winchester and Floyd, 1977) for Lushs Bight Group boninites. Stippled area is field of modern-day boninites 49

Figure 17: Zr/TiO_2 vs SiO_2 diagram (Winchester and Floyd, 1977) for Lushs Bight Group boninites. Stippled area is field of modern-day boninites 49

Figure 18: Zr/TiO_2 vs Nb/Y diagram (Winchester and Floyd, 1977) for selected non-boninitic Lushs Bight Group dykes and lavas 50

Figure 19: Zr/TiO_2 vs SiO_2 diagram (Winchester and Floyd, 1977) for selected non-boninitic Lushs Bight Group dykes and lavas 50

Figure 20: Modified Hughes (1972) plot illustrating Na and K changes during formation of spilites and alteration of boninites. Lushs Bight Group boninites and modern boninites are solid diamonds and crosses, respectively. (Data source for modern boninites is Jenner, 1981, 1982) 50

Figure 21: Modified Hughes (1972) plot illustrating Na and K changes during formation of spilites and alteration of selected Lushs Bight Group dykes and lavas. Note that the lavas are generally more highly altered than the dykes 50

Figure 22: Log Cr vs Mg#, Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure 51

Page

Figure 23: Log Ni vs Mg#, Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure 51

Figure 24: Ti vs Cr discriminant diagram, Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS. LKT—low-potasium tholeiites, OFB—ocean floor basalt. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure 52

Figure 25: Ti vs V discriminant diagram (Shervais, 1982), Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS. Labelled lines represent constant Ti/V ratios. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure 52

Figure 26: Ti vs Zr discriminant diagram (Pearce and Cann, 1973), Lushs Bight Group (A—lavas, B—dykes, C—boninites). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings 53

Figure 27: Zr/Y vs Zr discriminant diagram (Pearce and Norry, 1974), Lushs Bight Group (A—lavas, B—dykes, C—boninites). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings 53

Figure 28: Ti—Zr—Y discriminant diagram (Pearce and Cann, 1973), Lushs Bight Group (A—lavas, B—dykes, C—boninites). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings 54

Figure 29: Nb/Th vs Y discriminant diagram (Swinden *et al.*, 1989), Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. Samples in the non-arc field are 1543344, 1542013, 1542027 and 1542034 55

Figure 30: Primitive mantle normalized extended REE patterns for boninitic rocks of the Lushs Bight Group (A—Mg# 70-77; B—Mg# 58-69) 55

Figure 31: Primitive mantle normalized extended REE patterns for IAT lavas, Lushs Bight Group 56

Figure 32: REE-pattern fields for the different Lushs Bight Group lava groups (combined ICP-MS and TF-XRF data) 57

Page

Figure 33: Primitive mantle normalized extended RFE patterns for LOTI lavas, Lushs Bight Group 57

Figure 34: Primitive mantle normalized extended REE pattern for Lushs Bight Group non-arc lavas. The three samples averaged are 1542013, 1542027 and 1542034 58

Figure 35: Primitive mantle normalized extended REE patterns for Lushs Bight Group dykes (A-boninites, B-IAT (type I and II) and LOTI, C-CAB) 59

Figure 36: Primitive mantle extended REE patterns for felsic rocks, Lushs Bight Group (A—felsic volcanic, B—felsite—epidosite dyke) 59

Figure 37: Sm—Nd isotopic data for the Lushs Bight Group and comparison with other Ordovician Newfoundland volcanic rocks. Non-arc and arc fields based on about 80 isotopic determinations and ICP-MS analyses from volcanic rocks in ophiolites and volcano-sedimentary sequences throughout central Newfoundland (Jenner *et al.*, 1990; Swinden *et al.*, 1990). DMM = depleted MORB mantle (based on range for N-MORB today, White, 1985; von Drach *et al.*, 1986); VDM = very depleted mantle, estimated extreme for depleted mantle. IAT, ATM, BONINITE and RARC fields correspond to our range for island-arc tholeiites, arc-transitional-MORB, boninitic and refractory arc-volcanic rocks. Continental crust field based on average present day value of ϵNd = -16 and average upper continental crust composition (Taylor and McLennan, 1985) 60

Figure 38: Schematic map illustrating the distribution of the geochemical groups within the Lushs Bight Group (see text for explanation) 61

Figure 39: Summary diagram linking stratigraphic, geochemical and isotopic characteristics of the Lushs Bight Group. Note that symbols and patterns are keyed to Figure 38 (transitional ARC—sample 1542024; ARC—average of samples 1542249, 1542036, 1542266, 1542267, 1542151 and 1542004; depleted ARC—sample 1542116, and boninites—average of samples 1542118, 1542206 and 1543361) 62

Figure 40: Schematic diagram summarizing tectonic, stratigraphic, geochemical and isotopic features of ophiolitic and volcano-sedimentary groups in western Notre Dame Bay. Arrow on the right side indicates way-up. Inset in lower right corner illustrates ophiolite stratigraphy of the Lushs Bight Group, cut by dykes indicating possible link to the younger island-arc groups (+), and to the back-arc basin groups (x). Note that crosscutting relationships between the CAB and MORB dyke 'types' were not observed 63

Figure 41: Metaluminous vs peraluminous plot for the Colchester and Cooper's Cove plutons 63

Figure 42: Rock classification plots for Colchester and Cooper's Cove plutons 63

Figure 43: Ternary plots depicting the tectonic classification of the Colchester and Cooper's Cove plutons 64

Figure 44: Rb vs Y + Nb discriminant diagram for the Colchester and Cooper's Cove plutons 64

Figure 45: Primitive mantle normalized plot for plutonic rocks of the Colchester and Cooper's Cove plutons (Samples 1542226, 1542229, 1542271, 1542272, 1542275, 1542311 and 1543324). Comparison field and pattern for later calc-alkalic dykes and a Lushs Bight Group felsite—epidosite dyke overlapped. Normalizing values after Hofmann (1988) 64

Page

Figure 46: Location and listing of sulphide prospects and deposits within the Lushs Bight Group (Table 7 describes those not listed here or discussed in text) 66

Figure 47: Schematic diagram illustrating the stratigraphic settings of mineralization within the Lushs Bight Group, the Betts Cove and Bay of Islands ophiolites 69

Figure 48: Fault-controlled discharge site and mineralization in an hydrothermal system. Mineralizing fluids move up along the zones of weakness producing stockwork alteration and exhalative massive sulphides (shaded area) (from Saunders, 1985; modified after Adamides, 1980). ACT—actinolite; ALB—albite; CHL—chlorite; Cu—copper; EPI—epidote; QTZ—quartz; and Zn—zinc 70

Figure 49: Deformation of a generalized volcanogenic massive sulphide deposit by a combination of simple shear and later pure simple shear (Sundblad, 1980). (values = 0, 1, 3, 6 and 12 respectively parallel to the original layering and later pure shear (e = 0.5) applied perpendicular to the original layering; are effectively angular distortions when compared to the original model A 71

Figure 50: Variation in CaO and Na_2O across the end of the Whalesback ore zone (Bachinski, 1977). Section taken along the Whalesback Pond drainage tunnel with the portal being at 0 71

Figure 51: Variations in Na, Mn, and Cu in drill hole #132, Little Deer Mine (after Gale, 1969) (A—amphibole—feldspar porphyry; D—diorite; BAS—basaltic volcanic rocks; CS—chlorite schist) 72

Figure 52: Variations in Na, Mn and Zn content in 1350 level, Little Bay Mine (Gale, 1969). M—mafic dyke; D—diorite dyke; B—volcanic rocks; CS—chlorite schist; ■ > 1 percent Cu; ••• < 1 percent Cu 73

Figure 53: Geology of the Miles Cove Mine property showing the location of the Miles Cove and Jerrys Harbour prospects, Sunday Cove Island (Howse and Collins, 1979) 79

Figure 54: Diamond-drill section for diamond-drill holes 112-5, 6, Miles Cove Mine 80

Figure 55: Diamond-drill section for diamond-drill holes 112-1, 2, 13, and SC-4-67, Miles Cove Mine 81

Figure 56: Geological map of the Little Bay Mine area showing dyke concentrations (Douglas *et al.*, 1940, and MacLean, 1947) 85

Figure 57: Perspective isometric drawing of part of the Whalesback Mine showing development and mining methods between the 130 m (425 ft.) level and surface (adapted from drawing by BRINEX personnel) 93

Figure 58: Geology of the Whalesback—Little Deer area (see Flemming, 1970) 95

Figure 59: Little Deer Mine development plan (after Baumgartl, 1974) 97

Figure 60: Location and setting of the Rendell-Jackman prospect 100

Figure 61: Location and geological setting of mineralization in the Colchester—McNeily area 102

Figure 62: Geology map of the McNeily area (see McArthur, 1971) 102

Page

Figure 63: Geology map of the Colchester area (see McArthur, 1971) 105

Figure 64: Location and geological setting of the Sterling prospect (see McArthur, 1973) 108

Figure 65: Section 9 700 E showing diamond-drill holes SP-68-8, 9 and 10, Sterling prospect (see McArthur, 1973) 109

Figure 66: Section 10 000 E showing diamond-drill holes SP-68-1, 5 and SP-60-41, Sterling prospect (see McArthur, 1973) 110

Figure 67: Location and geology of the (Lower) Twin Pond prospect (see McArthur, 1973) 112

Figure 68: Section 12 800 E showing diamond-drill holes SP-68-15 and 16, Twin Pond prospect (see McArthur, 1973) 114

Figure 69: Section 13 900 E showing diamond-drill holes SP-68-23 and SP-69-26, 27 and 39, Twin Pond (see McArthur, 1973) 115

Figure 70: Sketch maps of trenches on the Timber Pond prospects. The gold—silver zone is on the left and the massive sulphide showing is on the right (see Andrews and Walker, 1990) 117

Figure 71: Sketch plan of the Hearn gold prospect, Little Bay (see Snelgrove, 1935) 121

Figure 72: Sketch map of trenches in the area of the Hammer Down Main Zone. Also shown are the Rumbullion and Wistaria zones. Muddy Shag Zone is off the figure to the southwest (left) (see Andrews, 1990) 124

Figure 73: North—south cross-section through the Hammer Down Main Zone, looking west. Mineralized zones are solid black (see Andrews, 1990) 125

Figure 74: Geological sketch plan and diamond-drill hole location plan for the Silverdale area (see Minorex, 1981) 127

Figure 75: Diamond-drill hole section for diamond-drill holes SVD-2, 3, and 4, Silverdale (see Minorex, 1981) 128

Map 94-226: Geology and mineral occurrences of the King's Point map area . . . . in back pocket

Map 94-227: Whole-rock geochemistry sample locations of the King's Point map area . . . . in back pocket

Map 94-228: Geology and mineral occurrences of the Little Bay Island map area . . . . in back pocket

Map 94-229: Whole-rock geochemistry sample locations of the Little Bay Island map area . . . . in back pocket

PLATES

Page

Plate 1: Sheeted diabase dykes at Indian Head, Halls Bay 10

Plate 2: Pillow screen and diabase dykes, Indian Head, Halls Bay 11

Plate 3: Basaltic pillow lava of the Lushs Bight Group 12

Plate 4: Agglomerate developed within pillow lavas, Southern Arm, Lushs Bight Group 13

Plate 5: Chlorite schist developed in pillow lava (note the carbonate veins and pods) 13

Plate 6: Boudinaged diabase dyke in pillow lava, Wild Bight area, Lushs Bight Group 13

Plate 7: Variolitic basaltic pillow lava, Little Bay Mine area, Lushs Bight Group 14

Plate 8: Quartz amygdaloidal pillow lava, Little Bay Mine area, Lushs Bight Group 14

Plate 9: Basaltic pillow lava with epidotized cores and chloritized rims, Lushs Bight Group 14

Plate 10: Pillow breccia and isolated pillow lava, Birchy Cove Head, Lushs Bight Group 15

Plate 11: Bedded tuffaceous rocks, Sunday Cove Island, Lushs Bight Group 15

Plate 12: Interpillow jasper lenses near the stratigraphic top of the Lushs Bight Group, Nickey's Nose Point 16

Plate 13: Silicified (?) pyroclastic breccia, McNeily Mine area, Lushs Bight Group 17

Plate 14: Photomicrograph of chlorite from unmineralized chlorite schist, Lushs Bight Group (crossed nichols, 10x) 18

Plate 15: Photomicrograph of chlorite from mineralized chlorite schist, Lushs Bight Group (crossed nichols, 10x) 20

Plate 16: Folding of the composite fabric in a chlorite schist, Lushs Bight Group 22

Plate 17: Satellite image (CCRS Airborne SAR) showing the prominent linears affecting the Lushs Bight Group and surrounding rocks 23

Plate 18: Interbedded argillite and red chert overlying the Lushs Bight Group, Fox Neck 25

Plate 19: Intrusion breccia showing hornblendite intruded by quartz diorite, Brighton gabbro 26

Plate 20: Monoclinal fold in an antiformal stack, 'Overlying Sequences', Triton Island 34

Plate 21: Folded chlorite schist hosting disseminated and stringer sulphides, Miles Cove Mine, Sunday Cove Island 82

Plate 22: Delaney Prospect shaft and dump, Little Bay Arm 83

Plate 23: Little Bay Mine (ca. 1960). 23a: view of headframe; 23b (page 87): view of mining complex from tailings pond 86

Plate 24: Aerial view looking northeast of Little Bay Mine glory-hole in the foreground (ca. 1988) 88

Page

Plate 25: Pyrite and minor chalcopyrite lens within chlorite schist, Little Bay Mine glory-hole 89

Plate 26: Chalcopyrite—pyrite vein with black chlorite inclusions, Little Bay Mine dump 90

Plate 27: Whalesback Mine. Top: area view of the Whalesback Mines site; Bottom: Whalesback mill about 10 years after mine closure (ca. 1983) 94

Plate 28: Whalesback Mine. Remnants of mill and headframe on left; tailings pond on extreme left, cave-in in centre (ca. 1988) 94

Plate 29: Little Deer decline (ca. 1983) 96

Plate 30: Black chlorite fragments within pyrite—chalcopyrite, Little Deer Mine 98

Plate 31: Tectonic banding defined by quartz-pyrite and quartz-lithic fragments, Little Deer Mine 99

Plate 32: Waste and ore dumps at the Rendell-Jackman property (ca. 1983) 100

Plate 33: Banded pyrite and chalcopyrite—sphalerite, Rendell-Jackman prospect 101

Plate 34: Waste and ore dumps, Sterling Prospect (ca. 1983) 107

Plate 35: Lady Pond prospect with dumps and old shafts (ca. 1983) 115

Plate 36: Banded pyrite, Nickey's Nose prospect 120

Plate 37: Gold-bearing quartz-carbonate veins in chlorite schist, Hearn Prospect (ca. 1983) 121

TABLES

Page

Table 1: List of theses on the geology and mineralization of the Lushs Bight Group 6

Table 2: Electron microprobe analyses of chlorites from the Lushs Bight Group 19

Table 3: Composition of Lushs Bight Group lavas (ICP-MS). Each geochemical type is listed by decreasing Mg# 38

Table 4: Composition of Lushs Bight Group dykes (ICP-MS). Each geochemical type is listed by decreasing Mg# 40

Table 5: Average compositions for major geochemical groups within the Lushs Bight Group lavas and dykes 42

Table 6: Sm—Nd isotopic data for Lushs Bight Group volcanic rocks 44

Table 7: Listing of showings, indications and prospects in the Lushs Bight Group not discussed in the text 74

Table 8: Assay results of grab samples collected from old mine dumps and workings 78

Table 9: Results of diamond drilling on the Miles Cove Mine by M.J. Boylen Engineering Company 1957 (ten Cate, 1957) 80

Table 10: Assays of grab samples from the Delaney mine dump (from Anderson, 1984) 84

Table 11: Production data from the Little Bay Mine for the period 1961 to 1969. (Source: MODS files) 89

Table 12: Whalesback Mine production for the period 1965-71 (Source: MODS files) 94

Table 13: Summary of diamond drilling carried out by M.J. Boylen Engineering Company and Cerro Mining Company on the McNeilly property (from McArthur, 1971 and Gibbs, 1967) 103

Table 14: Diamond-drill results, Colchester Mines (by M.J. Boylen Engineering Company), (from Brown, 1967) 104

Table 15: Assay results of diamond drill holes on the Colchester 'Main' Zone by M.J. Boylen Engineering Company and Cerro Mining Company (from McArthur, 1971) 105

Table 16: Results of diamond drill holes by M.J. Boylen Engineering Company and Cerro Mining Company on the Old English property (from McArthur, 1971) 106

Table 17: Assays of grab and channel samples from the Hearn Prospect (modified after Snelgrove and Howse, 1934) 122

Table 18: Assay results of grab samples and diamond drill core on the Silverdale property (see Minorex, 1981) 128

ABSTRACT

The map area lies within the Notre Dame Subzone of the Dunnage Zone, and includes the original type section of the Lushs Bight Group located at Lushes Bight, Long Island; however, the original type section is no longer considered part of the group, instead, it forms part of the Cutwell Group.

Rocks typically of what is generally accepted as Lushs Bight Group underlie most of the map area. The Lushs Bight Group is divided into a number of units based on rock type, and consist of mainly sheeted diabase dykes and basaltic flows and minor pyroclastic and ultramafic rocks. The pillow basalt is further subdivided based upon the presence of diabase dykes, pillow breccia, intercalated tuff, amygdules and hematization. The age of the group is not known directly, but it is inferred to be Cambrian and/or Early Ordovician based on the ages of surrounding fossiliferous rocks and dated intrusive rocks.

The group is bound by the Green Bay fault to the northwest and by the Lobster Cove fault to the south and east, which juxtaposes the group against the Silurian Springdale Group and the Ordovician Roberts Arm Group to the south; however, there are local outliers of the Springdale Group within the Lushs Bight Group. The Lushs Bight Group is conformably overlain by the Early Ordovician Western Arm Group in the north and is faulted against Cutwell Group-type rocks on the northeast coast of Sunday Cove and Pilley's Island. It is unconformably overlain by Carboniferous sedimentary rocks in the King's Point area. It has been intruded by numerous small gabbro bodies, by large Ordovician plutons that vary from mafic to granodiorite and tonalite, and by granite and porphyry of Siluro-Devonian age.

Both the dykes and lavas of the Lushs Bight Group can be subdivided into three major geochemical groups; these are i) boninites, ii) low-Ti tholeiites and iii) island-arc tholeiites. The boninitic rocks appear to represent the earliest stage of volcanism in the evolution of the group. Subsequent volcanism involved less refractory mantle sources and gave rise to the 'low-Ti tholeiites' and 'island-arc' volcanic rocks. The bulk of the Lushs Bight Group demonstrates a well-developed island-arc geochemical signature. The presence of selected diabase dykes and boninitic rocks favours a supra-subduction zone tectonic environment, i.e., in a fore-arc setting during the early stages of island-arc formation.

The deformation in the Lushs Bight Group is inhomogeneously developed. The intensity of the associated foliation decreases upward. It is steeply dipping but may vary to either side of vertical and the trend of the foliation varies from northeasterly to southeasterly. It is usually a L-S fabric associated with a steep stretching lineation and is defined by fine grained chlorite and fibrous amphibole. The regional foliation is interpreted to be axial planar to large-scale folds. The group is also characterized by the development of chlorite-schist zones parallel to subparallel to the regional foliation. The chlorite-schist zones contain a composite fabric resulting from the superimposition of a regionally developed fabric on an older inhomogeneously developed fabric, possibly in a shear zone. There are at least three directions of post-folding faults.

The main period of metamorphism in the Lushs Bight Group predated the regional deformation and is characterized by extensive epidotization. It is most strongly developed in the pillow lavas and generally decreases in intensity upward. It is interpreted to be a sub-seafloor alteration developed during the formation of the group. Metamorphism related to the regional deformation was mainly limited to growth of chlorite and fibrous amphibole along the foliation, and forms augen around epidote grains.

The Lushs Bight Group contains numerous base-metal sulphide showings and prospects. In addition, there are a number of epigenetic, structurally controlled, vein-hosted showings and prospects. The volcanogenic mineralization generally occurs in chlorite schist derived from the host mafic volcanic rocks and is not stratigraphically controlled. The chlorite-schist zones are interpreted to represent original hydrothermally altered, stockwork zones now transposed into the plane of the regional foliation. The mineralization consists mostly of pyrite with lesser amounts of chalcopyrite, pyrhotite, sphalerite and gold. Most of the mineralization is disseminated and stringer stockwork type; however, massive sulphides, with and without exhalative textures also occurs.

INTRODUCTION

LOCATION AND ACCESS

The Lushs Bight Group underlies the Springdale Peninsula, Sunday Cove Island and part of Pilley's Island and the Southwest Arm area, Notre Dame Bay, northern Newfoundland (Figures 1 and 2). These areas comprise the west half of map area NTS 2E/12 (Little Bay Islands) and east half of map area NTS 12H/9 (King's Point), effectively bounded by 49°30' and 49°45' north latitude and 55°30' and 56°15' west longitude.

Access to the area is from the Trans-Canada Highway via the Springdale, King's Point, Little Bay and Robert's Arm roads, and via boat from any of the coastal communities. Halls Bay, Little Bay, Little Bay Arm, Southern Arm and Southwest Arm provide well-exposed coastal sections through the area. A network of woods-roads permits accessibility to most of the inland terrain.

PREVIOUS WORK

The Lushs Bight Group and its mineralization has had a long history of study and exploration. Interpretations of the genesis of the group and the mineralization have differed dramatically over the years. A brief, chronological presentation of previous work is given below. (See Economic Geology Introduction section (page 65) for a more detailed discussion of the theories on the genesis of the sulphide mineralization.)

The geology of western Notre Dame Bay was first investigated in 1864 by Alexander Murray, who assigned the volcanic rocks to the middle division of the "Quebec Group". Geological studies were continued intermittently until 1909 by Murray and later by his assistant and successor, J.P. Howley (Murray and Howley, 1881, 1918). The results of their studies were summarized on Howley's 1905 geological map of Newfoundland, which showed all of western Notre Dame Bay as underlain by one unit described as "Serpentine, diorites, dolerites, etc." By the early 1900s many of the mineral prospects had been studied in some detail, as mining had commenced in the region prior to Murray's work and many of the showings known today are located on Howley's map (Howley, 1905). Murray, was aware of the association of the copper ores at Little Bay with volcanic rocks, which he described as "an exceedingly ferruginous mass of chloritic slate rock" (Murray and Howley, 1881, page 499). An account of the mining industry at the peak of its development was given by Wadsworth (1884). Sampson (1923) studied the ferruginous cherts associated with the volcanic rocks of Notre Dame Bay and suggested that they were formed as colloidal precipitates in a marine environment enriched in silica by the volcanic activity. Snelgrove (1928), in his collation of the geology of central Newfoundland, referred to the western part of Notre Dame Bay and southern environs as the 'Central Mineral Belt'.

Regional geological studies by the Geological Survey of Newfoundland during the 1930s represent the next major contribution to the geology of western Notre Dame Bay. Espenshade (1937), working in the Pilley's Island area, defined the Lushs Bight Group as the basalt-dominated upper division of the Pilleys Series. MacLean (1947) also assigned the rocks on the Springdale Peninsula to the Lushs Bight Group as defined by Espenshade (*op. cit.*). He divided the group into the Halls Bay Head section, Little Bay Head section and the conformably overlying Early Ordovician Western Arm section. This age is based on one brachiopod shell collected from a shale bed 4900 feet northwest of Clam Pond (MacLean, 1947). The Lushs Bight Group was thus considered Ordovician in age. Snelgrove (1935, 1938), Douglas *et al.* (1940) and Snelgrove and Baird (1953) included the mineralization in the Lushs Bight Group in their report on the mineral deposits of Newfoundland.

The area was subsequently included in 1:250 000 scale studies by the Geological Survey of Canada (Williams, 1962; Neale and Nash, 1963; Neale *et al.*, 1960). They generally agreed with MacLean (1947), although Neale and Nash (1963) inferred that there was more tight folding than previously recognized. Williams (1962) discontinued the use of the term "Pilleys Series", and based on the presence of early Middle Ordovician fossils in the Cutwell Group, considered the Lushs Bight Group as defined by MacLean (1947) to be older than the Cutwell Group. He interpreted the relationship between the two as a fault. Williams (1962) included rocks on the west side of Southwest Arm—Green Bay in the Lushs Bight Group. However, Hibbard (1983) reassigned these rocks to the Betts Cove ophiolite complex.

Williams (1963) noted the association of base-metal mineralization with lower Paleozoic basic volcanic sequences. Peters (1967) demonstrated the association of mineralization in the Springdale Peninsula with chloritic shear zones in metamorphosed basalts of the Lushs Bight Group.

The increase in mining and mineral-exploration activity in the 1950s and early 1960s coupled with the

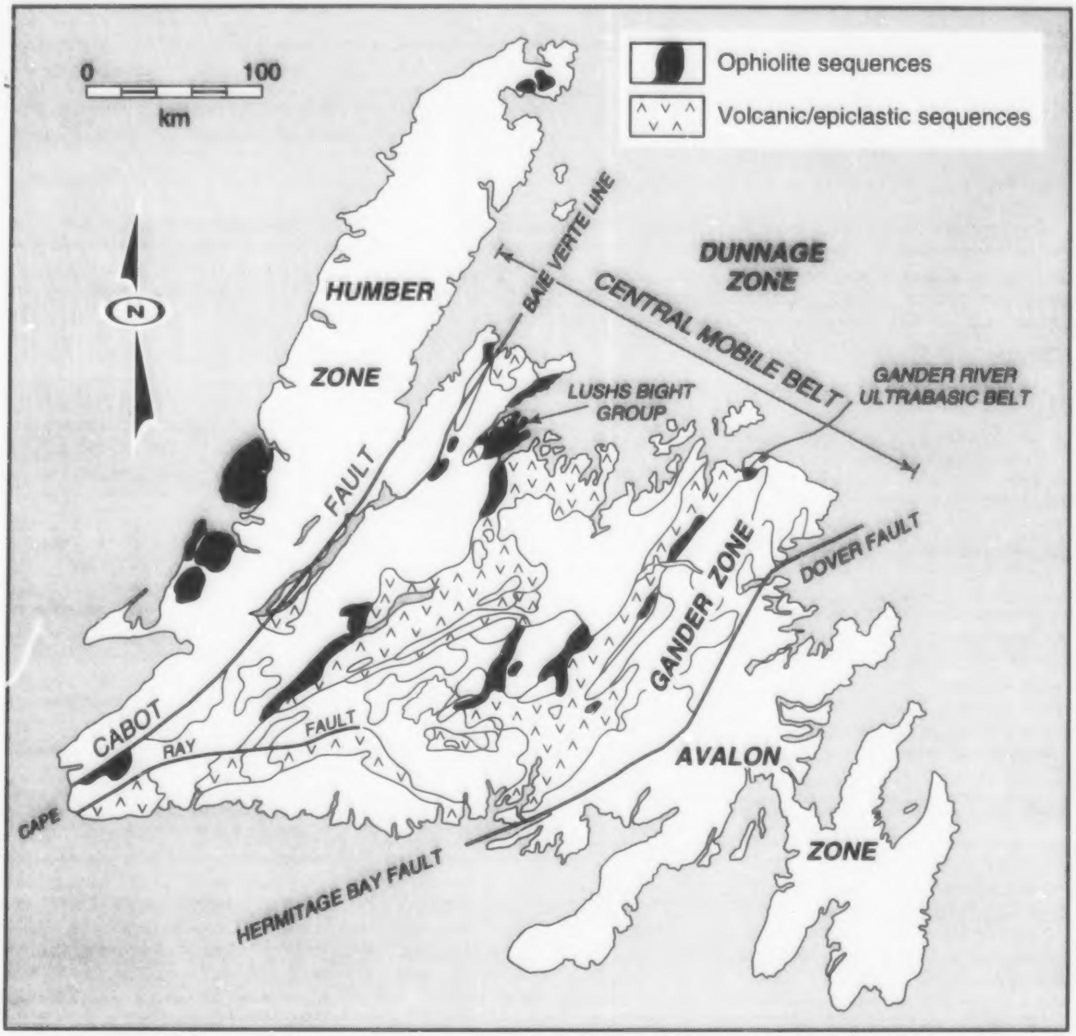
0
100
km
N
Ophiolite sequences
Volcanic/epiclastic sequences
HUMBER
ZONE
BAIE VERTE LINE
DUNNAGE
ZONE
CENTRAL MOBILE BELT
LUSHS BIGHT GROUP
GANDER RIVER ULTRABASIC BELT
FAULT
GANDER ZONE
DOVER FAULT
CABOT
RAY
FAULT
CAPE
AVALON
ZONE
HERMITAGE BAY FAULT

Figure 1. *Simplified geological map of Newfoundland with tectonostratigraphic subdivisions.*

advent of plate tectonics and the proposal that central Newfoundland formed as part of an early Paleozoic ocean (Wilson, 1966), resulted in a significant increase in geological studies in the area. Bird and Dewey (1970) and Dewey and Bird (1971) interpreted the Lushs Bight Group, which they referred to as the Little Bay Head Group, as oceanic crust. Papezik and Fleming (1967) and Fleming (1970) suggested the spilites and low-K tholeiites of the Lushs Bight Group in the Whalesback area could be oceanic tholeiites. Sayeed (1970), on the basis of the geology, setting and chemistry, interpreted the Colchester and Cooper's Cove plutons and the 'related' Lushs Bight Group as being of "island-arc" affinity.

Marten (1971a, b) redefined the Lushs Bight Group (MacLean, 1947) to include the Little Bay Head section and only the "basal basalt pillow-lava formation" of the Western Arm section. The revised Western Arm section was renamed the Western Arm Group (Marten, *op. cit.*). He identified two map units within the Lushs Bight Group in the Western Arm area, which he termed the 'main facies' and the 'black facies'.

Smitheringale (1972) interpreted the Lushs Bight Group on the basis of a regional petrochemical study of volcanic and subvolcanic rocks to be low-potash oceanic tholeiites formed at an oceanic ridge. He also suggested that the base-metal mineralization in the Lushs Bight Group was volcanogenic. DeGrace (1971) and Kennedy and DeGrace (1972) also suggested that the sulphide mineralization of the Lushs Bight Group was probably volcanogenic, although they felt that deformation played a role in economic concentration of the sulphides through remobilization and enrichment of chalcopyrite.

Strong (1972) described sheeted dykes in the Lushs Bight Group as evidence of its origin as oceanic crust. Strong (1973) interpreted the associated pyrite—chalcopyrite mineralization as typical of Cyprus-type ophiolite-hosted deposits.

Kanehira and Bachinski (1968) studied the mineralogy and textural relationships of the Whalesback ores and concluded that "sulphide mineralization ... must be post-volcanic lavas in part pre-shearing, and pre-regional metamorphism", i.e., "the present distribution of sulphides is a consequence of structural deformation".

Numerous detailed mapping and geochemical studies, generally sponsored by British Newfoundland Exploration Limited (BRINEX), were carried out in the late 1960s and early 1970s (see Appendix 1). These studies, many of which were university theses, were concentrated around showings and prospects, particularly the Whalesback and Little Deer properties. A partial listing of theses is given in Table 1.

Dean and Strong (1975) and Dean (1977) compiled the geology and mineral deposits data for the area on a scale of one inch to one mile. Kean *et al*. (1981) included the area as part of a 1:250 000-scale geological compilation of the Central Volcanic Belt. Dean (1978) summarized the regional geology of Notre Dame Bay, including the Lushs Bight Group.

PRESENT INVESTIGATION

This study is part of a contribution to the Canada—Newfoundland Co-operative Mineral Program, 1982-84. Under the program, regional metallogenic studies were undertaken in order to establish a stratigraphic and structural framework for the Lushs Bight Group and its contained mineral deposits and showings. The studies sought to evaluate the economic potential of the group and the economic significance of the mineralization, and to develop a metallogenic model that could be used in the search for further economic mineral deposits.

The field component of this project was carried out in 1982 and 1983 (Kean, 1983, 1984). The principal results include, a) identification of mappable but discontinuous lithological subdivision within the Lushs Bight Group; (the major rock units are sheeted dykes and pillow lavas, which constitute components of an ophiolite[1] stratigraphy, but are interpreted on the basis of geochemistry to have formed in a 'suprasubduction zone' environment as an incipient island arc), b) redefinition of the boundaries of the Lushs Bight Group and assign some previously included rocks to adjacent and overlying sequences of the Catchers Pond and Cutwell groups, c) recognition of a significant and distinctive, time-stratigraphic cover sequence of argillite and jasper (iron formation) containing pyrite and magnetite; (these rocks are included with the overlying sequences by precedence, but, should be more properly considered as part of the Lushs Bight Group), d) documentation of the extensive faulting, including probable thrusting in at least two directions, which has resulted in a diamond-shaped structural block pattern, e) a suggestion that structural repetition by faulting and folding accounts for the large exposure area of the Lushs Bight Group, f) the conclusion that sulphide mineralization is volcanogenic, and generally occurs in chlorite-schist zones that are shear zones developed within hydrothermally altered mafic volcanic rocks, and g) that gold mineralization is mesothermal and is structurally controlled.

The results of the field studies have been published in preliminary Open File Maps 8706 (King's Point; Kean and Evans, 1987a) and 8707 (Little Bay Island; Kean and Evans, 1987b).

PHYSIOGRAPHY

The regional physiographic features of western Notre Dame Bay have been described by Twenhofel and MacClintock (1940) who recognized a level of erosion at 305 m and another at 152 to 215 m. MacLean (1947) noted the northeast-trending topographic 'grain' was defined by ridges and valleys. This topographic 'grain' reflects both lithological and structural control. In many areas, bedding is reflected in the trends of the ridges and varies from northeast to southeast. The strong northeasterly grain of the country generally reflects erosion along fault zones. The long bays and arms (fiords) characteristic of the area are flooded valleys developed along these structures. The main drainage patterns and lake orientation also reflect the prominent northeast structural trend. North-

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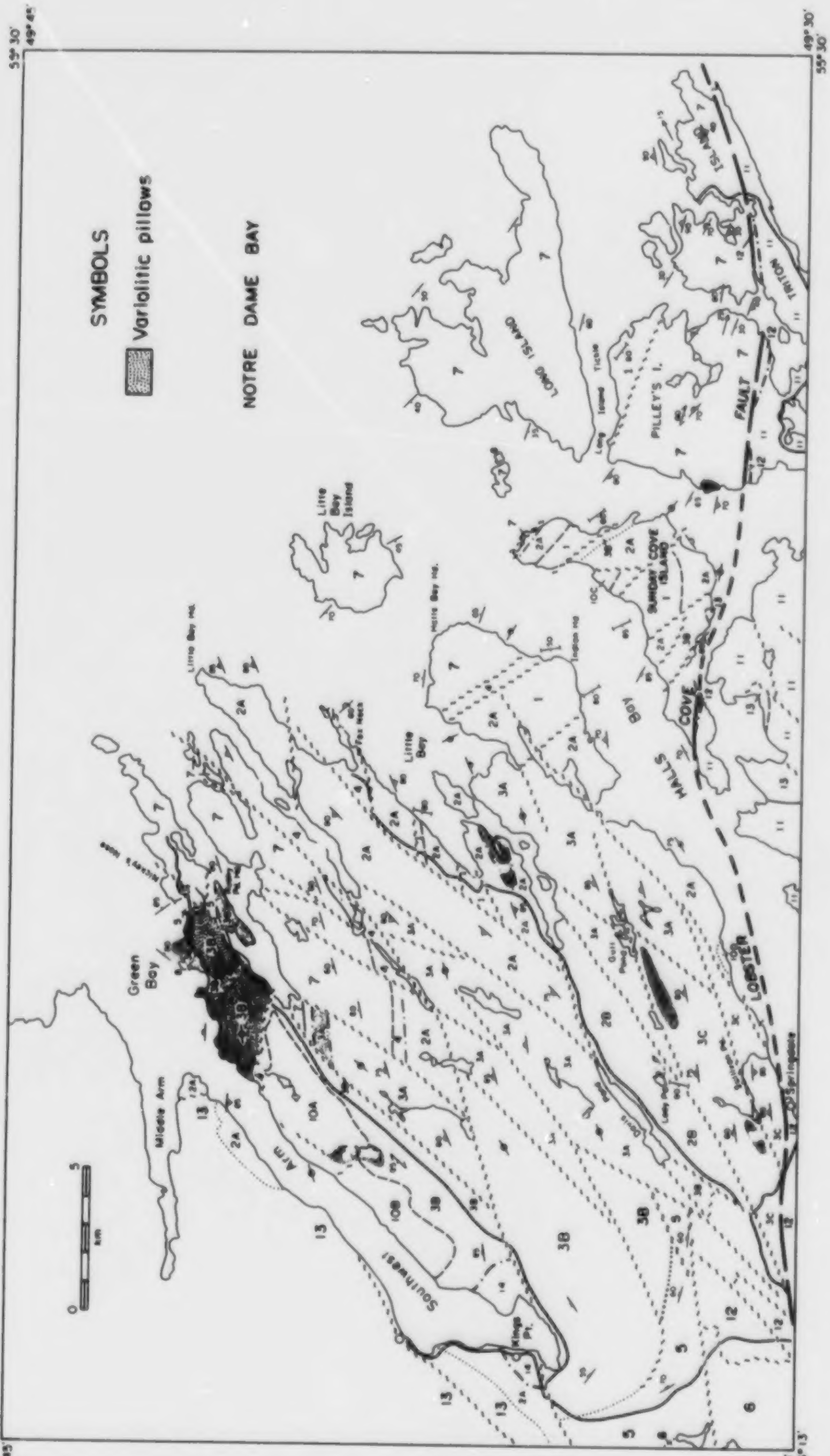
[1] refers to a rock association, as in the Steinman Trinity


SYMBOLS
Variolitic pillows
NOTRE DAME BAY
Green Bay
Middle Arm
Southwest Arm
Kings Pt.
Little Bay Island
Little Bay
Little Bay Hd.
Notre Dame Bay Hd.
LONG ISLAND
Long Island Tickle
PILLEY'S I.
SUNDAY COVE ISLAND
HALLS BAY
Gull Pond
Springdale
LOBSTER COVE FAULT
TRITON
0
5
km
55°30'
49°45'
56°15'
49°30'

LEGEND

CARBONIFEROUS

14	*Reddish-brown to greyish-red conglomerate and sandstone; grey shale and siltstone and minor limestone*

SILURIAN TO DEVONIAN

13	*Pink to red granite, granodiorite and quartz-feldspar porphyry*
12	SPRINGDALE GROUP: *red and brown conglomerate, sandstone and siltstone; minor volcanic rocks*

EARLY TO MIDDLE ORDOVICIAN

11	ROBERT'S ARM GROUP: *undivided mafic and felsic volcanic rocks*
10	**10A,** Colchester Pluton: *medium-grained diorite, quartz diorite and minor granodiorite.* **10B,** Coopers Cove Pluton: *fine- to coarse-grained diorite, granodiorite and granite, common diabase.* **10C,** Wellmans Cove Pluton: *medium-grained diorite and quartz diorite along with mafic and ultramafic inclusions.* **10D,** Bob Head Pluton: *medium- to coarse-grained diorite, gabbro and quartz monzonite*
9	Brighton Gabbro: *medium- to coarse-grained hornblende clinopyroxene, hornblendite, gabbro, diorite and quartz diorite*
7	WESTERN ARM / CUTWELL GROUPS: *massive along with pillow basalt and andesite, locally feldsparphyric. Lithic and pyroxene crystal -lithic tuff, lapilli tuff, breccia and agglomerate. Epiclastic and sedimentary rocks*
8	*Highly vesicular pillow basalt and feldsparphyric andesite. Lithic and pyroxene crystal - lithic tuff, lapilli tuff and breccia. Interbedded red and green argillite and tuff*
6	CATCHERS POND GROUP: *silicic lava, agglomerate and tuff; massive basalt, pillow lava and agglomerate; thin beds of fossiliferous limestone and limestone conglomerate*
5	*Thinly bedded, grey-green and black, mafic tuff and volcanic sediment; minor red argillite and chert. Magnetite lenses and magnetite-rich tuff locally present; minor basaltic pillow lava*

EARLY ORDOVICIAN AND EARLIER

LUSHS BIGHT GROUP (Units 1 to 4)

4	*Black, locally hematized pillow lava, agglomerate and tuff with common interpillow and lenses of jasper. Overlain by thinly bedded, chocolate-brown argillite and interbedded red chert*
3A	*Fine grained to aphanitic, grey to green, epidotized pillow lava with common diabase and gabbro dykes*
3B	*Fine grained to aphanitic, grey to green, commonly epidotized pillow lava with extensive pillow breccia and isolated pillows in places. Intercalated mafic tuff, locally extensive*
3C	*Fine grained to aphanitic, grey to green, commonly epidotized pillow lava and extensive chlorite schist; highly variolitic and quartz amygdaloidal in places. Mafic agglomerate, breccia and tuff; minor dacitic rocks. Extensive diabase dykes in places and locally sheeted*
2A	*Fine grained to aphanitic, grey-green to green, epidotized pillow lava with extensive diabase and gabbro dykes. Minor agglomerate and breccia. Chlorite schist extensive in places*
2B	*Undivided sheeted dykes and pillow lava with extensive dykes; locally variolitic. Minor mafic agglomerate, breccia and tuff. Minor dacitic rocks*
1	*Sheeted diabase dykes; locally with gabbro and pillow lava screens*

Figure 2. *Geological map of the Springdale Peninsula showing distribution of the major rock types in the Lushs Bight Group. Stippled areas consist of variolitic pillow basalt. (Ultramafic rocks are too small to be shown on this map.)*

Table 1. List of theses on the geology and mineralization of the Lushs Bight Group

Author	Subject	Findings/Results
Espenshade, 1937	Geology and mineral deposits of the Pilley's Island area.	Subdivided the Pilleys Series into upper (Lushs Bight Group) and lower (Cutwell Group) divisions.
MacLean, 1947	Geology and mineral deposits of the Little Bay area.	Mapped the Springdale Peninsula and subdivided the Lushs Bight Group into Western Arm and Little Bay Head sections.
Morris, 1966	The Sullivan Pond prospect.	Concluded that mineralization was epithermal.
James, 1967	The geology of the Buckshee Brook area.	Detailed map of this area.
Penny, 1968	Geology east of Springdale.	Detailed map of this area.
Donohoe, 1968	Structure and stratigraphy of the Halls Bay Head area.	Detailed map and regional interpretation.
Gale, 1969	Primary dispersion of Cu, Zn, Ni, Co, Mn and Na adjacent to the Little Bay and Little Deer mines and the Lady Pond prospect.	Demonstrated that the host rocks were altered by epigenetic-hydrothermal fluids.
Fleming, 1970	Petrology of the volcanic rocks of the Whalesback area.	Distinguished two chemical groupings of metabasalts, the Whalesback and St. Patricks.
McGonigal, 1970	Geology of the Springdale Group west of the Little Bay road.	Described the contact between the Lushs Bight Group and the overlying Springdale Group as an unconformity. Interpreted the plutons to be genetically related to the rocks of the Lushs Bight Group.
Peters, 1970	Geology of the Nickey's Nose—Harry's Harbour area.	Detailed map and description.
Sayeed, 1970	Tectonic setting of plutons of the Colchester area.	Concluded the plutons were pretectonic and probably related to the Lushs Bight Group.
DeGrace, 1971	Structure and stratigraphic setting of sulphide deposits south of King's Point.	Interpreted that the sulphide mineralization is hosted by pretectonic chlorite-schist zones.
Marten, 1971a	Geology of the Western Arm Group.	Redefined the Western Arm section of MacLean (1947) as the Western Arm Group.
West, 1972	Structure and genesis of the Little Deer deposit.	Concluded that the deposit appeared to have formed after the volcanic rocks in which it is enclosed.
McArthur, 1973	Geology and mineralization of the Sterling prospect.	Interpreted the deposit to be a disseminated "stockwork" zone of "Cyprus type" affinity.
Bachinski, 1973	The author included some of the mineral deposits of the Lushs Bight Group in his study of the affects of metamorphism on cupriferous iron sulphide-rich ophiolitic rocks.	Concluded that the alteration in the chlorite schist at Whalesback was associated with ore formation.

Table 1. Continued

Author	Subject	Findings/Results
Dean, 1978	Volcanic stratigraphy and metallogeny of the Notre Dame Bay area.	Produced geological compilation maps, and documented the mineral deposits of the Notre Dame Bay area.
Anderson, 1984	Geology and setting of the Delaney prospect.	Concluded that it was a shear-zone-hosted volcanogenic sulphide prospect.
Szybinski, 1995	Paleotectonic and structural setting of western Notre Dame Bay area.	Identified major thrusts and nappes in western Notre Dame Bay area.

northeast-trending arms, bays and brooks reflect a subsidiary, north-northeast-trending fault system. Over the whole area, the drainage is in a youthful stage of development. Relief within the area is generally in the order of 60 to 120 m. Several prominent ridges reach an elevation in excess of 200 m and a number of hills are higher. Blow-Me-Down Hill, south of Southern Arm is the highest at 268 m. The hills, particularly those inland, vary from steep sided to rounded, resulting in a semi-rugged, rolling landform.

The area was glaciated during the Wisconsin glaciation and is covered by an ubiquitous, though usually thin, blanket of coarse till. A large outwash deposit of glaciofluvial—glaciomarine sand and gravel underlies the town of Springdale. Erratics, generally coarse-grained granitoids, are common. Ultramafic erratics occur in the valleys formed by the South Brook and Western Arm faults. Bedrock exposure varies from excellent on the coast to poor in inland valleys and lowlands.

A dense growth of spruce and balsam fir, interspersed with minor birch and aspen, covers most of the area. The hilltops are in places barren. Bogs, swamps, lakes and ponds underlie much of the low-lying areas and valleys.

REGIONAL SETTING

The Lushs Bight Group is part of the Paleozoic Central Mobile Belt of the Newfoundland Appalachians (Figure 1) and lies within the Notre Dame Subzone (Williams *et al.*, 1988) of the Dunnage tectonostratigraphic zone of Williams (1976, 1978a, b, 1979). The Dunnage Zone is characterized by remnants of a series of Cambrian and Ordovician island-arcs and back-arc basins that were successively accreted to the North American (Laurentian) and Gondwanan continental margins during the Ordovician and Silurian. The geological development of the Dunnage Zone is recorded in four very broad geological environments:

1) Cambro-Ordovician ophiolitic rocks, which have historically been interpreted as remnants of oceanic crust. Recent evidence suggests some of these complexes formed in a supra-subduction zone environment.

2) Thick sequences of Cambrian and Ordovician tholeiitic and calc-alkaline volcanic and subvolcanic rocks, and related volcaniclastic rocks. The volcanic sequences consist of mafic and felsic, dominantly submarine, volcanic and volcaniclastic rocks generally interpreted to represent the remains of Cambrian to Middle Ordovician island-arc and back-arc basins.

3) Middle Ordovician shale and chert, and a Late Ordovician to Early Silurian flyschoid sequence of argillite, greywacke and conglomerate. Generally, these rocks conformably overlie many of the volcanic sequences and are in part derived from them; however, along the western side of the Dunnage Zone, these rocks are absent and Silurian volcanic and sedimentary rocks rest unconformably on either ophiolitic rocks, Ordovician volcanic island-arc rocks, or Ordovician plutonic rocks. The flyschoid sequences are generally derived from the northwest and indicate tectonic uplift to the northwest during the Taconian Orogeny.

4) Subaerial, mainly felsic, volcanic rocks and terrestrial—fluviatile sedimentary rocks of Silurian age. They are interpreted to be deposited in troughs and basins (successor basins) developed within the orogen and unconformably overlie the Ordovician and older rock units. Carboniferous sedimentary rocks were deposited in later pull-apart basins.

A variety of plutonic rocks related to variation in the geological environment range in age from Cambro-Ordovician to Siluro-Devonian and minor Jurassic dykes and minor plugs.

The Lushs Bight Group is confined to the area north of the Lobster Cove Fault (Figure 2) (Espenshade, 1937), the "Lushs Bight terrane" of Horne and Helwig (1969), and forms part of the Notre Dame Bay nappe (Szybinski *et al.*, 1991) that forms the structurally highest nappe in the Notre Dame Subzone. The Lobster Cove Fault forms the southern and eastern boundary of the nappe. The northwest boundary is marked by the Green Bay fault. The Lobster Cove Fault juxtaposes the Lushs Bight Group against the Silurian Springdale Group and the Ordovician Roberts Arm Group to the south. There are local outliers of the Springdale Group within the Lushs Bight Group, north of the Lobster Cove Fault. Generally, these rocks are also fault-bounded; however, an unconformity may exist between the Lushs Bight Group and the overlying Springdale Group in the Davis Pond area (McGonigal, 1970). The Lushs Bight Group is conformably overlain by the Lower Ordovician Western Arm Group in the north. It is faulted against unassigned rocks, probably belonging to the Cutwell Group, on the northeast coast of Sunday Cove and Pilley's islands. The contact with the Catchers Pond Group is not well documented, although it is probably a fault-modified, conformable contact. In the King's Point area, the Lushs Bight Group is intruded and overlain by the Siluro-Devonian King's Point complex and it is unconformably overlain by Carboniferous sedimentary rocks.

The Lushs Bight Group, along with the Betts Cove, Advocate, Point Rousse, South Lake, Shanadithit Brook, Star Lake, Annieopsquotch and King George IV Lake complexes, the Gander River Ultrabasic Belt and others, had previously been interpreted to be ophiolitic basement to the Dunnage Zone. However, new evidence presented in this report suggests the Lushs Bight Group was formed in a suprasubduction zone. The Lushs Bight Group has historically been considered correlative, on the basis of age and stratigraphic position, with the Betts Cove ophiolite complex.

GENERAL GEOLOGY

INTRODUCTION

The Lushs Bight Group is a mafic volcanic sequence consisting predominantly of a monotonous succession of strongly epidotized, mafic pillow lava, massive flows, minor intercalated pillow breccia, agglomerate and tuff. Locally, excellent examples of sheeted diabase dykes are preserved. Gabbroic dykes, sills and stocks and rare ultramafic rocks are also present (Figure 2).

The strong epidote alteration, which is so characteristic of the Lushs Bight Group, decreases upward in the group and is significantly less well developed in the overlying sequences. The alteration accompanied or predated the early stages of the regional deformation.

The contact with the overlying non-ophiolitic assemblages of the Western Arm, Cutwell and Catchers Pond groups, and unassigned rocks on Pilley's and Triton islands is faulted, but locally may be conformable (Marten, 1971a, b; Kean 1983, 1984). Despite shearing, an apparent conformable relationship between the Lushs Bight Group and overlying sequences is exposed in the Fox Neck and the Nickey's Nose areas. At these localities, pillow basalt of the Lushs Bight Group is overlain by interbedded red chert and chocolate-brown argillite locally containing sulphide and magnetite iron formation. Fine-grained, green tuff and chert, yellow-green tuff, grey and black argillite, and siliceous argillite first appear as thin interbeds in the red and brown sediments but form the main rock type within 100 m. Minor intercalated pillow lava occurs in the lower parts of the sedimentary sequence. Coarse pyroclastic breccia and pyroxene—plagioclase crystal vitric tuffs overlie the sedimentary rocks.

Papezik and Fleming (1967) and Fleming (1970) recognized two petrochemical volcanic types in the Whalesback area: i) St. Patricks type, considered to be stratigraphically higher, is spilitic and characterized by chloritic alteration; ii) Whalesback type is tholeiitic and characterized by epidote alteration. Marten (1971a, b) recognized a 'black' facies and 'main' epidote facies within the Lushs Bight Group in the Western Arm area.

The Lushs Bight Group is intruded by various plutonic rocks of probable Ordovician age including the Colchester and Cooper's Cove plutons and many small stocks and plugs interpreted to be contemporaneous with volcanism. Rocks similar to the Brighton gabbro intrude sheeted diabase dykes on Pilley's Island. The Brighton gabbro was reported by Stukas and Reynolds (1974) to give an ^{40}Ar—^{39}Ar radiometric age of 495 ± 5 Ma. However, Szybinski (1995) cited three ^{40}Ar—^{39}Ar ages of 473 ± 2.2, 473 ± 2.4 and 475 ± 2.6 Ma and a U—Pb zircon age of 478.5 ± 4.5 Ma. Felsic and granitic stocks, plugs and dykes related to the overlying volcanic sequences intrude the Lushs Bight Group.

The Lushs Bight Group is structurally complex. It is folded into a number of northeast-trending anticlinoria and synclinoria. Later folding and flexuring about north—south axes has resulted in southeast trends. Major northeast-trending faults cut the major fold structures. North-northeast- and northwest-trending faults are also present. Many of these fault systems may have a thrust component. Monoclinal folding, probably part of an antiformal stock related to thrusting is seen in the overlying sequences on Pilley's and Triton islands.

The present large area of exposure is interpreted to be a result of structural repetitions and the true thickness of the group is probably between 3 and 4 km.

In the text, the symbol units refer to units and subunits illustrated in Maps 226, 227, 228 and 229, which accompany this report.

LUSHS BIGHT GROUP

Definition and Division

The Lushs Bight Group was originally defined by Espenshade (1937) in the Pilley's Island area as a sequence of predominantly mafic volcanic rocks constituting the upper part of the Pilleys Series, the type section being located at Lushes Bight on Long Island. He interpreted the Lushs Bight Group as conformably overlying the predominantly volcaniclastic Cutwell Group, the lower part of the Pilleys Series.

MacLean (1947) divided the rocks underlying the Springdale Peninsula into three sections. The Halls Bay Head section, a volcaniclastic and pillow basalt sequence, in the southeast which was in fault contact with the Little Bay Head section, a sequence of monotonous pillow lavas, underlying most of the central part of the peninsula, and the Western Arm section, a sequence of predominantly volcaniclastic rocks with intercalated pillow lava gradationally overlying the Little Bay Head section in the northwest. He correlated the Western Arm section with the Halls Bay Head section on the basis of lithology. In turn, he correlated the Halls Bay Head section with rocks along strike on Sunday Cove Island and included the rocks on the Springdale Peninsula in the Lushs Bight Group. MacLean (1947) found a single brachiopod of the subfamily *Acrothelinae* and the genus *Discotreta* near the base of the Western Arm section, which indicated an Early Ordovician, probably late Canadian (?Arenig) age. The Lushs Bight Group is intruded by the Middle Ordovician Brighton gabbro (Szybinski, 1995). Williams (1962) demonstrated that the Cutwell Group was younger than the Lushs Bight Group and the two were in fault contact. The age of the Lushs Bight Group was thus considered Early Ordovician and older. Williams (1962) and Kean (1973) redefined the Lushs Bight Group to exclude rocks on Long Island, including the type section, from the Lushs Bight Group.

Marten (1971a, b) also considered the contact between the Little Bay Head and Western Arm sections as gradational. However, Marten (1971a, b) restricted the Lushs Bight Group to the Little Bay Head section and the "Basal basalt pillow-lava formation" of the Western Arm section. The redefined Western Arm section was renamed the Western Arm Group.

The Lushs Bight Group is now considered to include only those stratigraphic elements that define an ophiolite stratigraphy, i.e., mafic pillow lava, massive flows, minor breccia and agglomerate, sheeted diabase dykes, gabbro dykes and sills and small bodies of ultramafic rock.

The group is bound to the south and east by the Lobster Cove and Catchers Pond faults, and to the northwest by the Green Bay fault. To the northeast, it is overlain by younger volcanic rocks, which are either conformable or juxtaposed along faults such as the MacLean and Long Tickle faults. The Lushs Bight Group can be divided into a number of fault-bounded blocks defined by the intersection of north-northeast- and northeast-trending faults. The geology within each block is fairly homogeneous, generally consisting of a single stratigraphic or rock unit (e.g., sheeted dykes or pillow lava).

The major units are mafic volcanic rocks and sheeted dykes. The most common rock type is fine-grained to aphanitic, epidotized pillow basalt. Pillow breccia, tuff (generally aquagene), agglomerate and chert are locally present, but never extensive. Other rock units include gabbro dykes, sills and plugs and a number of small ultramafic bodies. The rock units are discussed on the following pages or below in an assumed 'ophiolite' stratigraphic order, i.e., ultramafic through to extrusive rocks.

Ultramafic Rocks

Distribution

Ultramafic rocks (LЄOμ) occur mainly in the western part of the Lushs Bight Group. A small pod occurs near the Rendell-Jackman prospect (Pit Pond area) south of King's Point (DeGrace, 1971) and four pods occur along or near the eastern shore of Southwest Arm within the Cooper's Cove Pluton. Another small pod was reported (location not known) approximately 1.5 km east of Browns Pond (Sayeed, 1970) near Tim Pond. It is noteworthy that these occurrences are located near the Green Bay and

Western Arm faults. Glacial erratics of ultramafic rocks are also common in these areas. Kean (1973) described an occurrence of carbonatized ultramafic rock on Pigeon Island in the Long Island Tickle fault zone, south of Long Island.

The bodies occurring within the Cooper's Cove Pluton may be xenoliths. However, Sayeed (1970) interpreted them to be "... tectonically squeezed into the volcanic and dioritic host rocks". Other occurrences within mafic volcanic sequences are characterized by shearing and lack of contact metamorphism and they generally occur in or close to fault zones. DeGrace (1971) described the Pit Pond occurrence as a "pluton".

Description

The ultramafic rocks are variably serpentinized peridotites and are typically brown-weathered and blue, blue-grey and brown on fresh surface, medium to coarse grained, equigranular, and veined by serpentine and chrysotile; no cumulate layering is present. Grains of magnetite and chromite(?) stand out on the weathered surfaces. The Tim Pond occurrence is a green serpentinite with carbonate cut by veinlets of chrysotile (Sayeed, 1970) and the Pigeon Island occurrence consists of a highly sheared and recrystallized, grey magnesite-rich, carbonatized ultramafic rock (Kean, 1973).

Petrography

Equidimensional, rounded grains of olivine, up to 2 mm in diameter, comprise more than 50 percent of the rock and are completely altered to serpentine (antigorite and veinlets of chrystolite), which contain secondary magnetite. Pyroxene is altered to tremolite and uralite occurs interstitial to, and poikilitically encloses, the olivine; carbonate and chlorite are also present. The principal accessory minerals are magnetite and chromite. The Pigeon Island occurrence consists of magnesite with disseminated magnetite, and actinolite—tremolite is also present (Kean, 1973).

Structure and Metamorphism

The ultramafic bodies are generally sheared and deformed although the Pit Pond occurrence has no apparent tectonic fabric (DeGrace, 1971). Most of the bodies occur in, or close to, major fault zones, i.e., Green Bay, Western Arm and Long Island Tickle faults. The primary silicate minerals have been altered to an assemblage of tremolite, serpentine, and carbonate, which are indicative of greenschist-facies metamorphism.

Contact Relationships

The contacts are not exposed but shearing and faulting are generally associated with the ultramafic bodies. No contact metamorphism was observed. Those in the Southwest Arm area have been interpreted as xenoliths within the Cooper's Cove Pluton and/or as phases of larger intrusive complexes. An interpretation as part of an ophiolite suite is a viable alternative.

Sheeted Dykes

Distribution

Sheeted diabase dykes (LЄOd) occur in the Little Bay and Indian Head areas (Plate 1), along the west side of Sunday Cove Island and on its east side at Paddox Bight, and along the north coast of Pilley's Island. Areas entirely underlain by dykes also occur north of St. Patricks, in the Lady Pond area, east of the Little Bay road and in isolated outcrops in the Sterling Pond area. They generally occur in fault-bounded blocks and commonly contain pillow lava screens in their upper part (Plate 2). The dykes occur in

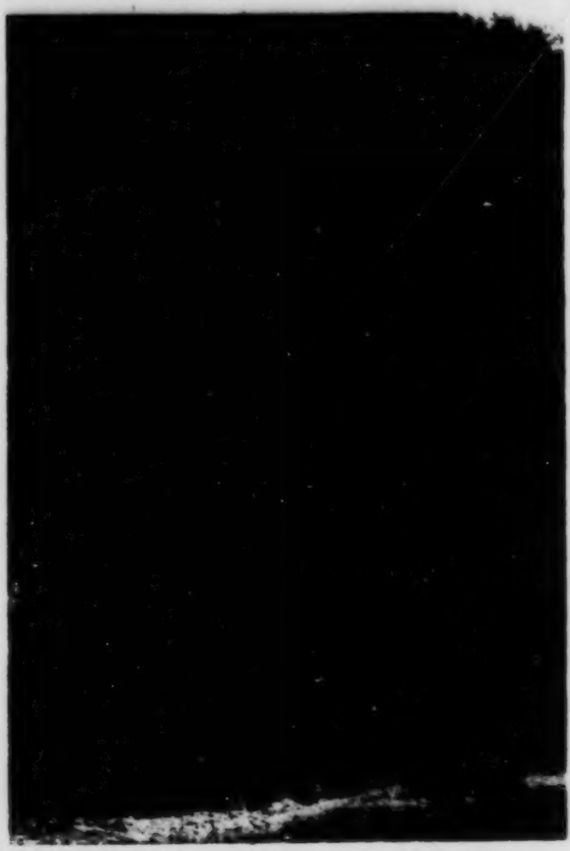


Plate 1. *Sheeted diabase dykes at Indian Head, Halls Bay.*

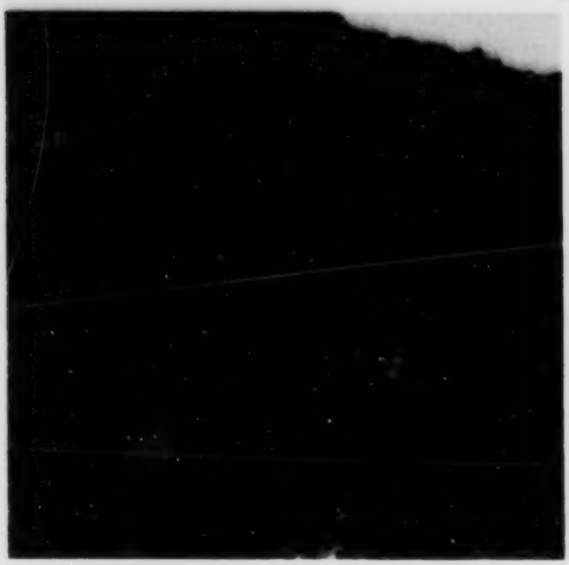


Plate 2. *Pillow screen and diabase dykes, Indian Head, Halls Bay.*

widely separated geographic areas. This may be due to structural repetition, original temporal and/or spatial relationships, different stratigraphic levels or combinations thereof. They are not assigned different ages or symbols on the accompanying maps.

Description

The dykes in the Little Bay, Springdale and Lady Pond areas trend slightly east of north, with slight local deviations, and dip steeply to the west. In the Halls Bay—Sunday Cove Island area, the dykes trend southeast, reflecting the regional change in strike, and dip to the southwest. The sheeted dykes generally contain abundant disseminated pyrite and form rusty-weathering scree slopes.

The units consist predominantly of fine- to medium-grained, grey, green and equigranular diabase and lesser coarse-grained diabase to fine-grained, equigranular and locally porphyritic gabbro. Epidote veins and pods are common and dykes completely replaced by epidote are locally present. Rare dykelets of aphanitic diabase (basalt) less than 10 cm wide are also present but are considered to be younger. Green and greenish-white, felsite or epidosite dykes are present in the sheeted complexes in the Little Bay road and Lady Pond area.

Individual dykes range from less than 0.25 m to 2 m and have an average thickness of about 0.5 m. The dykes display chilling on one margin, but locally, both margins are chilled against gabbro screens and larger gabbro dykes. The dykes grade into areas of dykes having pillow screens and, in the Little Bay area, into pillow lavas with extensive dykes. Dykes along the west shore of Sunday Cove Island, in particular the northern unit, are highly schistose and chloritic. Variolites are locally developed in the dykes, and are not restricted to the chilled margins.

Petrography

The diabase dykes are mineralogically and texturally similar although there are distinct chemical groupings (see Geochemistry section, page 36). The grain size is generally less than 1 mm and varies from aphanitic to fine grained.

The dykes display an intergranular to intersertal texture consisting of randomly oriented equigranular, subhedral to euhedral, stumpy plagioclase laths accompanied by mafic minerals and their alteration products. The plagioclase is variably saussuritized, and clouded with minute inclusions of calcite and epidote; the matrix plagioclase in the fine-grained rocks are in places inclusion free and fresh. The plagioclase is albite to oligoclase (up to An_{30}), and locally, andesine is present and the grain boundaries are indistinct, feathery and embayed. The crystals of plagioclase display lamellar albite and Carlsbad—Albite twins, which are locally bent and/or fractured due to strain.

The clinopyroxene (augite) is altered to green, pleochroic actinolite and uralite; however in places, simple-twinned crystals of augite are preserved. Interstitial secondary minerals include epidote, chlorite, calcite and minor quartz and small veinlets of quartz are also present. Accessory minerals include pyrite, leucoxene, magnetite and sphene.

The felsite or epidosite dykes consist of extensive granular epidote having fine-grained intergranular amoeboid quartz, sericite and calcite. Veinlets of recrystallized quartz and epidote are present locally.

Structure and Metamorphism

In general, there is no ubiquitous, regional penetrative fabric developed in the sheeted dykes. However, a weak inhomogeneous fabric defined by chlorite is present locally. Strongly developed shear zones defined by chlorite schist are inhomogeneously developed on the west side of Sunday Cove Island. They are characterized by slickensided chlorite schist and tectonically banded rocks of mylonitic appearance, which in places, resemble bedded tuffs. Boudins are locally developed. The shear zones have gradational boundaries and are generally associated with faults.

The trend of the dykes changes from northerly in the central part of the area to southeasterly in the eastern part of the area. These changes are a result of open folding and flexuring about north—south-trending axes. The dykes have been metamorphosed under lower greenschist-facies conditions, as indicated by the assemblage actinolite—tremolite, chlorite, epidote, calcite, albite and quartz.

Contact Relationships

The sheeted dykes within the Lushs Bight Group are in most places faulted against pillow lavas. The upper parts of the sheeted dykes contain pillow lava screens and in the Little Bay area are gradational into overlying pillow lava. The sheeted dykes on Pilley's Island are faulted against pyroclastic rocks belonging to the overlying sequences. Contact relationships or stratigraphic position of sheeted dykes in the Sterling Pond area, north of Springdale, are unknown.

Volcanic Rocks

Distribution and Division

Mafic lava flows and minor pyroclastic rocks comprise about 95 percent of the Lushs Bight Group. They underlie most of the study area, except for Long Island, Pilley's Island, Triton Island and the Western Arm area. They occur in fault-bounded blocks that may account for their large geographic area underlain by the unit. The lack of distinctive rock type or stratigraphic markers makes structural reconstruction difficult. It is also not possible to consistently correlate units on the basis of geochemistry (see Geochemistry section, page 36).

The mafic volcanic rocks are subdivided into a number of units based on the predominance of a particular rock type. These subdivisions are not necessarily stratigraphic but represent distinguishable lithological features in a monotonous sequence of mafic flows. The main subdivisions are: i) pillow lava with extensive dykes (L€Opd), particularly in the lower parts of the pillow sequence, ii) pillow lava (L€Op), which is further subdivided by the presence of extensive pillow breccia and isolated pillows (L€Opx) and tuff (L€Opt), iii) extensively quartz amygdaloidal, locally variolitic, pillow lava and massive flows, tuffs and minor felsic pyroclastic rocks (L€Opa), and iv) grey black to black, locally hematitized pillow lava with common to extensive red chert predominantly developed in the upper part of the Lushs Bight Group (L€Opb) (equivalent to the 'black facies' of Marten, 1971a, b). Areas of extensive variolitic and generally quartz amygdaloidal pillow lava, which are commonly associated with mineralization, are stippled on Figure 2. Diabase and gabbro intrusions (L€Og) are locally extensive and are indistinguishable from massive flows in many places. They are considered a part of the volcanism. Chlorite-schist zones derived from the mafic volcanic rocks are inhomogeneously but ubiquitously developed (see Structure and Metamorphism section, page 32).

Papezik and Fleming (1967) and Fleming (1970) divided the volcanic rocks in the Little Bay Arm area into the 'Whalesback' and 'St. Patricks' types on the basis of chemistry. Sayeed (1970) divided rocks in the Jackson's Cove area into the Jackson's Cove and Birchy Cove units on the basis of physical, petrological and chemical characteristics of the pillow lava. DeGrace (1971) divided parts of the volcanic rocks in the King's Point area into different facies e.g., close-packed pillows and pillow breccia, roughly corresponding to the subdivisions of L€Opx and parts of L€Opt and Ot. Marten (1971a, b) divided the Lushs Bight Group in the Western Arm area into the 'main' (L€Op) and the 'black' (L€Opb) facies on the basis of alteration.

Description

The mafic volcanic rocks of the Lushs Bight Group are essentially a thick monotonous sequence of basaltic pillow lava (Plate 3), with lesser amounts of massive flows and minor intercalated tuff, breccia and agglomerate (Plate 4) and dykes and sills. These rocks are locally transformed to chlorite schists (Plate 5).

Plate 3. *Basaltic pillow lava of the Lushs Bight Group.*

In places, it can be established that a gradational contact exists between the sheeted dykes and overlying pillow lava. Above the sheeted dykes with pillow screens, the sequence passes from pillow lava and extensive dyke

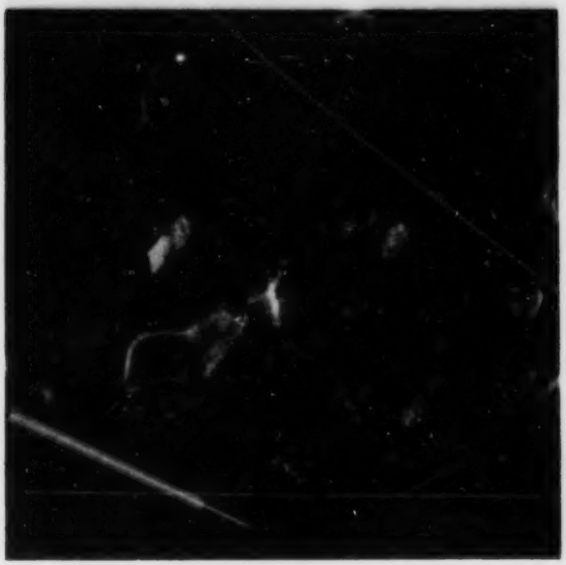


Plate 4. *Agglomerate developed within pillow lavas, Southern Arm, Lushs Bight Group.*

Plate 5. *Chlorite schist developed in pillow lava (note the carbonate veins and pods).*

swarms (L€Opd) to predominantly pillow lavas (L€Op), but still locally containing extensive, individual to multiple dykes.

Little Bay Head and the north side of Little Bay are characterized by extensive dykes in pillow lava (L€Opd). In the Little Bay Head area, there are sections more than 50 m thick that consist of multiple intrusions of green, equigranular, fine-grained gabbro and diabase dykes that individually, are as wide as 2 m. Locally, these extensive dyke sections are sheeted, i.e., individual dykes possess only one chilled margin. They strike slightly east of north at a high angle to the strike of the enclosing pillow lava. Epidote veins and patches are scattered throughout. In shear zones, the dykes are commonly boudinaged (Plate 6) and pyrite is a common constituent.

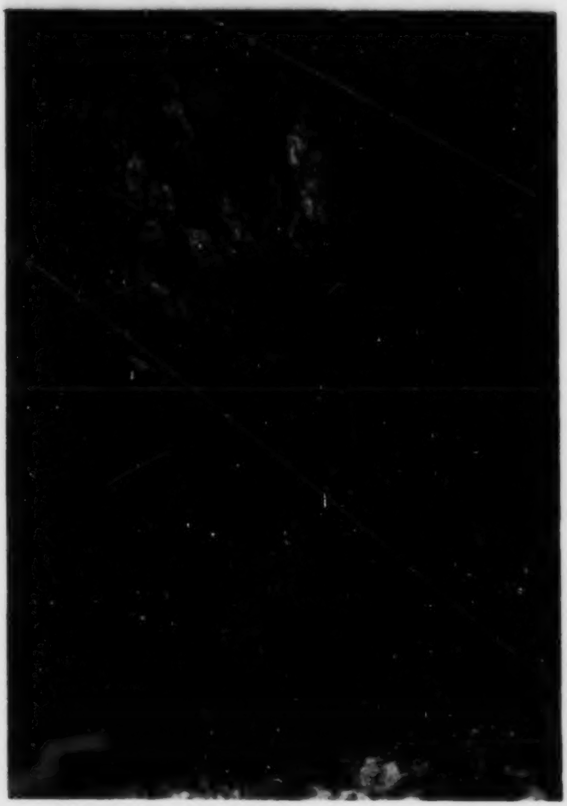


Plate 6. *Boudinaged diabase dyke in pillow lava, Wild Bight area, Lushs Bight Group.*

The pillow lavas (L€Op), characterized by thin rims and close packing, vary from 15 cm to 1 m in diameter and are round to elliptical. They are commonly flattened and moderately elongated in the plane of deformation. In the shear zones, the pillow lavas become chlorite schist, often enveloping epidote knots. Quartz veining, with or without carbonate, is locally extensive. The pillow lavas are fine grained to aphanitic, green to grey-green and equigranular and in most areas, they are generally nonvesicular, nonamygdaloidal and nonvariolitic. However, variolitic varieties (Plate 7) are well developed locally (e.g., Birchy Cove area, Shoal Arm area), and are particularly extensive in areas of sulphide mineralization where they are generally associated with quartz amygdules (Plate 8) such as Little Bay, Sleepy Hollow, Whalesback and Lady Pond. Although the variolitic varieties are spatially associated with the mineralization, there does not appear to be a stratigraphic control on their occurrence. They occur above, below and lateral to the mineralization.

Plate 7. *Variolitic basaltic pillow lava, Little Bay Mine area, Lushs Bight Group.*

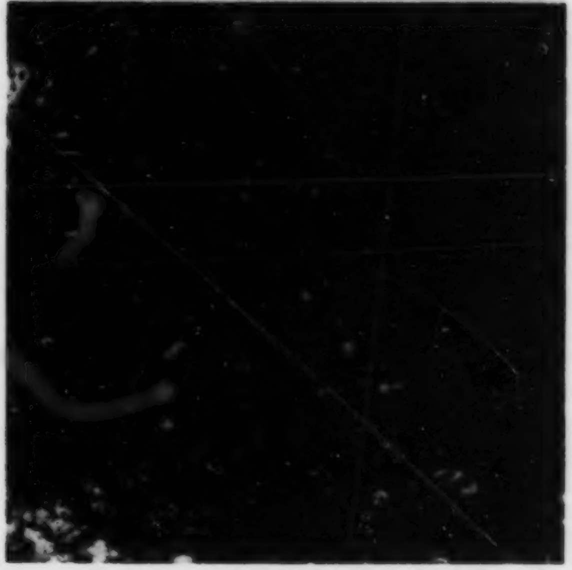


Plate 8. *Quartz amygdaloidal pillow lava, Little Bay Mine area, Lushs Bight Group.*

The variolites, locally up to 1 cm across and typically epidotized, are disseminated throughout the pillow lavas but are locally concentrated either in the cores or near the rims of the lavas.

Although there is commonly little interpillow material, white, grey, green and rare red interpillow chert are locally present, particularly near the Little Bay, Sleepy Hollow and Whalesback mines. In a few areas, interpillow aquagene tuff and minor breccia, pillow breccia and agglomerate are present. Small interpillow pillows and pillow fragments are abundant in places.

The pillows are variably epidotized, with the epidote occurring as veins, veinlets and pods or patches. The cores are, in places, completely replaced by epidote, which is itself enveloped by chlorite schist (Plate 9). There are local areas, particularly in shear zone, where chloritic alteration predominates. Pale-green, leached and silicified pillow lava and minor pillow breccia occur on the coast along strike from both the Little Bay and the Sleepy Hollow mines.

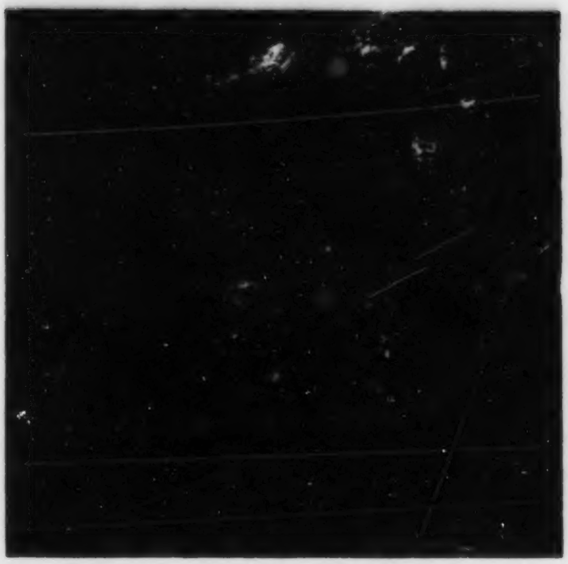


Plate 9. *Basaltic pillow lava with epidotized cores and chloritized rims, Lushs Bight Group.*

In the St. Patricks area, fine- to medium-grained, green, equigranular, massive mafic flows, and flows having poorly developed pillow structures and local vesicular and scoriaceous zones, are intercalated with the pillow lava. Resembling these flows are numerous gabbro dykes and sills up to 40 m wide, consisting of saussuritized yellow-green feldspar and a chloritized mafic mineral.

The pillow lava sequence (subunit L€Opx) exposed south of King's Point and in the Birchy Cove area, Southwest Arm, is characterized by extensive pillow breccia, isolated pillows (Plate 10) and thin units of finely bedded, green and grey, mafic tuff, lapilli and minor agglomerate (subunit L€Opt). Thin tuffaceous units (Plate 11) are locally developed elsewhere in unit L€Op, but is never extensive. Minor red argillite and jasper are present locally and resemble rocks immediately overlying the Lushs Bight Group, particularly those rocks in the Ketches Pond—Ovals Pond area (Ot). The presence of thick units of red

Plate 10. *Pillow breccia and isolated pillow lava, Birchy Cove Head, Lushs Bight Group.*

argillite and jasper generally is considered as the stratigraphic top of the Lushs Bight Group or the base of the overlying volcanic/volcaniclastic sequences.

Mafic volcanic rocks (L€Opa) in the Springdale area consist of pillow lava, massive flows, chlorite schists and, locally, sheeted diabase dykes. The pillow lavas are aphanitic to fine grained, green, closely packed and commonly are accompanied by breccia and tuff. They are locally variolitic and rich in quartz amygdules. Rare jasper occurs as isolated and boudinaged knots between 2 and 5 cm in size. Magnetite-bearing chert and rare magnetite lenses are also present. The massive flows are green, generally vesicular, fine grained, highly cleaved and, along with the chlorite schist, form an extensive part of the unit. In many areas, particularly north of the town of Springdale, the protolith for the chlorite-schist unit is difficult to determine, however, much of the chlorite schist may be derived from tuff. Locally, fine grained, green, dacitic crystal-lapilli tuff is developed, particularly in the area southwest of the Sterling prospect. Diabase and gabbro dykes are common and aphanitic, green, grey and grey-green felsic dykes are locally present.

The top part of the Lushs Bight Group is in many places characterized by dark grey to black, chloritic, commonly hematized and usually magnetic, pillow lava, breccia, agglomerate and massive flows (L€Opb). Epidote is generally restricted to veins, patches and pods. Interpillow and lensoidal jasper lenses increase in amount stratigraphically upward (Plate 12), and magnetite or magnetite-rich chert—tuff lenses are also locally present, e.g., at Shilly Cove. At both, Fox Neck and Nickey's Nose, upper units of the Lushs Bight Group are extensively epidotized but the epidote occurs as veins, irregular patches and in the matrix of breccias. These characteristics are irregularly developed and although they are characteristic of the upper part of the stratigraphy they do not define a stratigraphic unit.

Plate 11. *Bedded tuffaceous rocks, Sunday Cove Island, Lushs Bight Group.*

Felsic pyroclastic rocks are rare within the Lushs Bight Group. Felsic pyroclastic rocks and quartz—sericite schist have been reported from the Little Deer—Whalesback mines area (Peters, 1967; West, 1972). Dacite schist occurs as interdyke screens east of the Davis Brook. Dacite pyroclastic rocks are also present in the Sterling prospect area and altered and silicified pyroclastic breccia occurs near the McNeily prospect (Plate 13). Intercalated

Plate 12. *Interpillow jasper lenses near the stratigraphic top of the Lushs Bight Group, Nickey's Nose Point.*

felsic (or highly silicified) lapilli tuff is present in the Lady Pond area. It is worth noting that the all well-documented areas of felsic volcanic rocks are in areas of significant mineralization. It is not clearly understood where they all are actually felsic volcanic or alteration relative to mineralization.

The chlorite-schist zones within the mafic volcanic rocks form elongated or lenticular zones, from a few metres to more than 100 m wide, which pass gradationally into the weakly deformed host rocks. This gradation occurs over a distance ranging from one metre to tens of metres, depending on the width and intensity of the shear zone. The rocks in the shear zones are highly schistose so it is difficult to determine the protolith. The chlorite schist zones are not lithologically controlled, although they parallel the stratigraphy. Dykes in these zones are transposed into the plane of deformation and in places boudinaged (Plate 6). The chlorite schists are both mineralized and barren; however, they are generally more highly pyritized than the country rocks. One characteristic of the mineralized *versus* unmineralized shear zones is that chlorites from the highly mineralized shear zones are generally black whereas those from the unmineralized zones are green.

Diabase and gabbro dykes, sills and stocks occur throughout the entire sequence (L€Og). They are fine to medium grained, green and generally equigranular, although feldsparphyric phases are present. In most areas, it is very difficult to determine whether many of these rocks are intrusive or massive flows, and whether they are related to the volcanic rocks.

In addition to the gabbro and diabase dykes, sills and small stocks interpreted to be associated with the volcanic rocks, there are rare, relatively fresh diabase and basalt dykes that feed the overlying sequences. Also pink, red or orange aphanitic and quartz—feldspar porphyritic felsic dykes intrude the Lushs Bight Group and are related to felsic volcanic rocks in both the Catchers Pond and Springdale groups.

Porphyritic dykes are locally common, particularly in the Whalesback—Little Deer mines area north of the Little Deer Pond fault. They can be classified into four types containing either phenocrysts of feldspar, amphibole, amphibole and feldspar, or pyroxene in a green, aphanitic matrix. The dykes vary in width from several centimetres to several metres and trend either northwest or slightly east of north.

Aphanitic, felsite dykes (although most of these appear to be epidosites), in the Little Bay Road area, apparently unrelated to younger and overlying sequences are locally present. They occur associated with sheeted dyke sequences in the Sterling prospect area and in the vicinity of shear zones in the Whalesback area (Fleming, 1970) and elsewhere. Some of these dykes are probably trondhjemitic.

Petrography

The pillow lavas and pillow breccias of the Lushs Bight Group vary in the degree and type of alteration from area to area. Their primary mineralogy appears to have been predominantly plagioclase and clinopyroxene, with little variation in texture and grain size. Papezik (1966) gave the average mode of the basalts as follows: 35

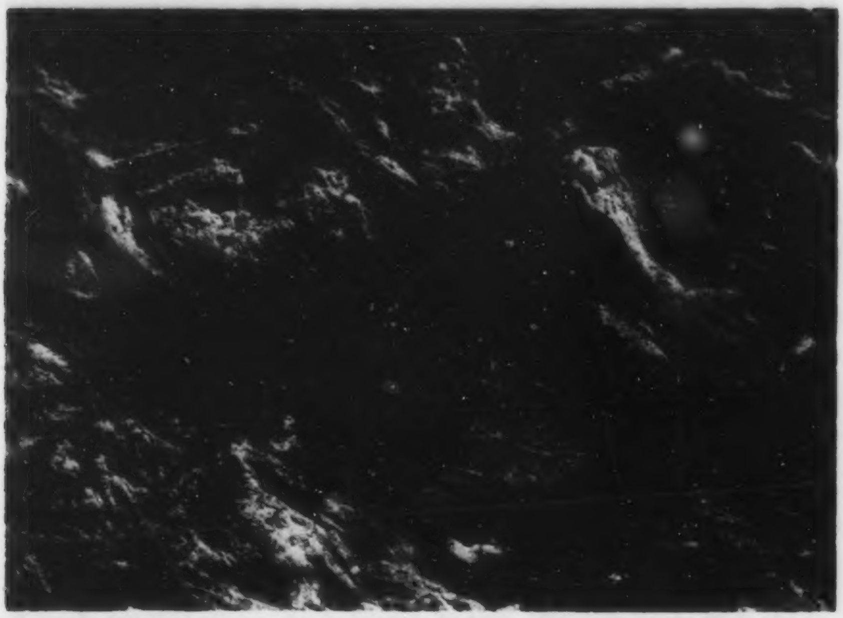


Plate 13. *Silicified (?) pyroclastic breccia, McNeily Mine area, Lushs Bight Group.*

percent albite, 25 to 30 percent clinopyroxene, 20 percent epidote, 10 to 15 percent chlorite, 2 to 5 percent opaques, accessories and other secondary minerals.

The rocks are generally fine grained but vary from aphanitic to medium grained. They consist of clinopyroxene in a matrix of feathery-feldspar microlites locally exhibiting pilotaxitic texture. The microlites form slender laths with indistinct, highly embayed, feathery boundaries. Albite twinning is most common but Manebach and Carlsbad twins are also present. The twinning is usually simple, or if multiple, comprising few lamellae. Fleming (1970) determined the composition of the plagioclase to vary from An$_5$ to An$_{10}$, i.e., albite. The microlites are variably altered, varying from limpid with minute inclusions to turbid. In places, the microlites are completely masked by the secondary alteration minerals epidote, calcite, chlorite, leucoxene and sphene.

Randomly distributed, anhedral to euhedral plagioclase microphenocrysts (less than 1 mm in length) with rare phenocrysts in places form a glomeroporphyritic texture. They vary from slender laths to stumpy, rectanglar forms. The grain boundaries are generally sharper than those of the microlites and the slender laths are commonly bent, broken and strained. In the schist zones, they are transposed to the plane of the foliation. The feldspars vary in composition from albite to andesine (up to An$_{34}$) and display albite and Carlsbad—Albite twins having both simple and polysynthetic structure. The plagioclase is variably saussuritized and varies from turbid with minute inclusions to being completely replaced by epidote, carbonate, albite and quartz.

Clinopyroxene, which is partially or completely altered to green actinolite or uralite, and in places to chlorite, is usually present as microphenocrysts occurring intergranular to the plagioclase microlites. Small grains ususally subhedral, colourless and twinned, are present in the groundmass but are rare. The twinning is generally simple, consisting of two individual twin seams.

Epidote is generally the most common alteration mineral. The epidote occurs as small, anhedral grains, either randomly distributed or forming aggregates intersertal to the plagioclase microlites. A turbid appearance is imparted by the presence of numerous dust-like inclusions of leucoxene, usually more abundant at grain boundaries. Epidote also occurs in veinlets and amygdules with and without quartz, chlorite and occasionally calcite. Although epidote is the most common alteration mineral, chlorite is more abundant in the St. Patricks type of Fleming (1970) and in the chlorite schist zones.

The chlorite, generally associated with green amphibole (actinolite?), occurs mainly in the groundmass but also replaces clinopyroxene. It also occurs in veinlets and amygdules, commonly associated with epidote. The chlorite is generally pale to medium green, slightly pleochroic and shows a greenish-brown to purplish-brown or -blue interference colour. Chlorites, from chlorite-schist zones that contain minor pyrite but no substantial base-metal mineralization, are pale-green to dark-green pleochroic and have olive-green and greenish-brown interference colours (Plate 14). They are pycnochlorite to ripidolite (Figure 3; Table 2). Chlorites from the mineralized chlorite schist zones are dark green, pleochroic and exhibit strongly Berlin-blue interference colours (Plate 15) and are brunsvigite to ripidolite (Figure 3). The chlorites from the mineralized schist zones are iron-rich relative to those from the host rocks and unmineralized schist zones (Figure 4) (see Economic Geology section, page 65).

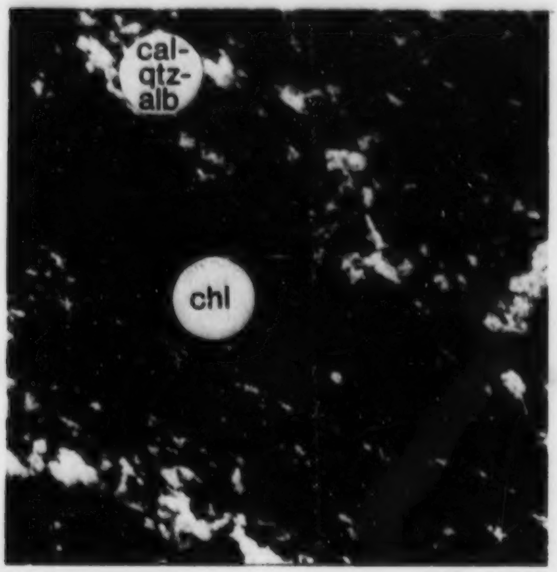


Plate 14. *Photomicrograph of chlorite from unmineralized chlorite schist, Lushs Bight Group (crossed nichols, 10x).*

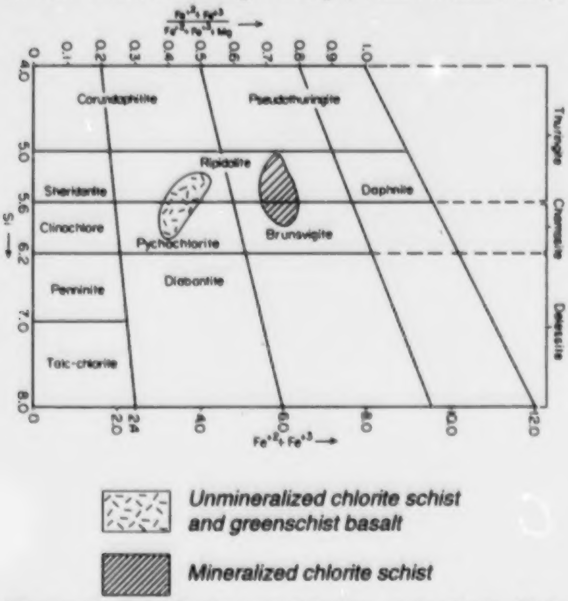


Figure 3. *Classification of chlorites of the Lushs Bight Group (after Hey, 1954).*

Calcite, and less commonly quartz, are present in the groundmass, as replacement of plagioclase and in amygdules and veinlets. Sphene, leucoxene, pyrite and magnetite occur disseminated throughout the groundmass. Sphene also occurs as aggregates in the matrix.

Variolitic textures are locally present. The varioles are altered to a mixture of epidote, actinolite, chlorite and rare quartz. However, locally the original radial texture is preserved and defined by plagioclase (albite?), actinolite and chlorite.

Areas of silicification, such as along strike from the Little Bay Mine, are texturally and mineralogically similar to the pillow basalts, except that they commonly have free quartz in the groundmass. Breccias at Lady Pond and McNeily (see Plate 13) locally consist of lensoid shaped, recrystallized, fine-grained quartzofeldspathic clasts which, in places, contain rare epidote and plagioclase grains. The matrix consists of fine-grained to cryptocrystalline feldspar, quartz and chlorite. The chlorite is pale green, slightly pleochroic and has bluish to purple blue interference colours. A weak foliation is defined in the groundmass by the chlorite. Chlorite also occurs as large clots, probably representing amygdules. Quartz amygdules and veins consist of equigranular, strained and recrystallized quartz displaying sutured and polygonal grain boundaries.

Bedded and banded tuffaceous rocks of subunit LЄOpt consist of a translucent to opaque matrix containing small fragments and crystals of feldspar (albite?), and rare lithic lapilli. Epidote grains and aggregates of epidote are also present. Pale-green, pleochroic chlorite having purplish-blue interference colours is finely disseminated throughout the matrix. Subhedral to euhedral pyrite occurs dispersed throughout the rock and quartz veinlets crosscut and parallel the banding.

Minor felsic crystal tuff, consisting of crystal and crystal fragments of quartz, oligoclase and rare lithic lapilli in a generally equigranular, quartzofeldspathic matrix, outcrops near Sterling Pond. Chlorite occurs both as unoriented grains and as aligned aggregates defining a foliation. The chlorite is pale green, slightly pleochroic and exhibits anomalous blue interference colours. Sericite is a minor constituent, associated with the chlorite. Pyrite and carbonate (calcite) are disseminated throughout the matrix and minor quartz veinlets are present. The quartz is generally equigranular, exhibits undulose extinction and embayed and sutured grain boundaries.

Dykes from Unit LЄOpd and intrusive rocks of Unit LЄOg are mineralogically similar to each other and to the flows. They are fine to medium, and locally, coarse grained having plagioclase and clinopyroxene crystals up to 2 mm across. The plagioclase morphology varies from slender laths to stumpy, euhedral crystals and varies in compositon from albite (An_5) to labradorite (An_{60}), with most being in the An_{30} range (Papezik, 1966). Plagioclase crystals are variably saussurtized, varying from turbid to completely altered to epidote and calcite. Clinopyroxene (augite?) occurs mainly as intergranular crystals, but

Table 2. Electron microprobe analyses of chlorites from the Lushs Bight Group

No.s	1	2	3	4	5	6	7	8	9	10	11	60	103	251	272
SiO_2	26.39	27.25	27.37	28.25	27.39	25.45	25.37	25.48	22.30	25.53	26.30	29.73	28.20	27.08	29.23
TiO_2	0.06	0.04	0.03	0.02	0.00	0.06	0.04	0.05	0.02	0.05	0.04	0.02	0.01	0.02	0.00
Al_2O_3	22.08	20.06	20.64	20.21	19.31	17.86	21.14	18.86	19.99	19.92	19.60	22.04	17.52	20.52	23.14
FeO*	24.70	22.30	24.93	21.30	21.53	35.29	30.68	31.87	33.73	34.70	29.71	22.26	20.98	19.95	21.61
MnO	0.14	0.26	0.30	0.25	0.27	0.17	0.29	0.20	0.15	0.42	0.25	0.33	0.33	0.29	0.24
MgO	15.11	17.74	16.79	19.50	18.47	8.26	9.58	10.11	9.15	8.43	13.66	19.14	19.11	18.77	17.76
CaO	0.01	0.02	0.02	0.02	0.02	0.20	0.02	0.03	0.0	0.02	0.02	0.09	0.02	0.00	0.08
Na_2O	0.02	0.05	0.00	0.07	0.06	0.02	0.03	0.01	0.0	0.91	0.02	0.07	0.0	0.05	0.07
K_2O	0.02	0.01	0.00	0.00	0.03	0.01	0.05	0.01	0.01	0.00	0.00	0.05	0.02	0.01	0.00
Total	88.55	87.73	90.09	89.68	87.07	87.13	90.88	86.65	85.37	90.00	89.64	93.75	86.21	87.17	92.14
No. of Cations on the basis of 28 O_2															
Si	5.457	5.632	5.575	5.667	5.685	5.714	2.763	2.828	5.120	5.534	2.805	5.695	5.903	5.576	5.674
Al	5.384	4.886	4.958	4.777	4.722	4.726	2.715	2.460	5.410	5.008	2.464	4.976	4.318	4.983	5.292
Ti	0.006	0	0	0	0	0.006	0.003	0.003	0	0	0.003	0	0	0	0
Fe	4.273	3.854	4.247	3.576	3.735	6.624	2.795	2.951	6.474	6.284	2.470	3.564	3.673	3.435	3.509
Mn	0.024	0.042	0.048	0.041	0.042	0.026	0.025	0.016	0.027	0.076	0.021	0.050	0.055	0.048	0.034
Mg	4.655	5.469	5.102	5.832	5.715	2.762	1.554	1.667	3.126	2.722	2.170	5.465	5.958	5.763	5.138
Ca	0	0	0	0	0	0	0	0.003	0	0	0	0.017	0	0	0.011
Na	0.006	0.018	0	0.023	0.024	0.006	0.006	0	0	0.381	0.003	0.022	0	0.018	0.05
K	0	0	0	0	0.006	0	0.006	0	0	0	0	0.011	0	0	0
$\frac{Fe^*}{Fe^*+Mg}$ =	0.47	0.41	0.45	0.38	0.40	0.71	0.65	0.64	0.67	0.70	0.53	0.39	0.38	0.37	0.41

FeO*, Fe* = total Fe
Key:
1-5 = Unmineralized chlorite schist. 6-11 = Mineralized chlorite schist; 6-Lady Pond, 7-Sterling, 8-Little Deer, 9-Little Bay, 10-Rendell-Jackman, 11-McNeily, 60, 103, 251, 272 = Normal greenschist volcanic rocks

locally as microphenocrysts. The clinopyroxene may contain simple twins and twin seams. It is variably altered to actinolite and rare chlorite. Epidote, sphene, leucoxene, chlorite, calcite, pyrite, rare magnetite and quartz occur intersertal to the plagioclase. Veinlets of epidote and chlorite with or without quartz and calcite are also present. The proportion of epidote and chlorite is variable, resulting in epidote- or chlorite-dominated rocks (see Papezik and Fleming, 1967; Fleming, 1970). In the plagiophyric dykes, the plagioclase is completely saussuritized. In some cases, the phenocrysts are microscopically indistinguishable from the altered groundmass.

The felsite dykes were described by Fleming (1970) as consisting essentially of plagioclase microlites in a fine-grained groundmass of sericite, chlorite, epidote, calcite and leucoxene. They are thus probably trondhjemites.

The dark-grey to black basalts that characterize the upper part of the Lushs Bight Group (i.e., black facies) were described by Marten (1971a, b) as follows:

> "In places the basalt is fairly fresh and consists chiefly of clinopyroxene and labradorite (An_{64}) showing typical intergranular and subophitic textures with intersertal pools of chlorite. Generally, however, there has been much alteration to chlorite, epidote and uralitic hornblende. The interstitial alteration products marginally corrode plagioclase laths which are zoned, turbid and more sodic -- An_{33} -- than in the fresher rock, reflecting progressive albitisation under the influence of low-grade metamorphism. Amoeboidal patches of quartz replace the groundmass and in places

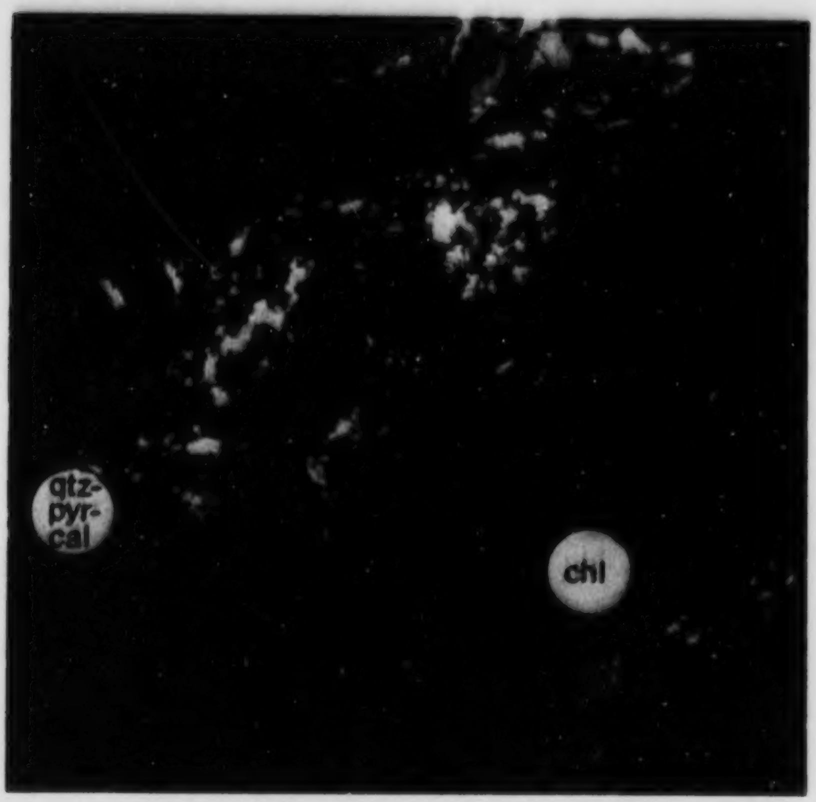


Plate 15. *Photomicrograph of chlorite from mineralized chlorite schist, Lushs Bight Group (crossed nichols, 10x).*

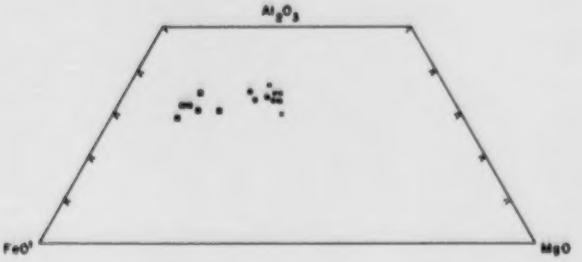


Figure 4. *AFM plot of chlorite compositions:* ■—*mineralized chlorite schist;* ●—*unmineralized chlorite schist; X—greenschist basalt.*

poikilitically enclose altered plagioclase laths. A good cleavage defined by aligned chlorite and fibrous uralite tends to augen around some of the larger grains of epidote, and the quartz blebs are strained and have developed some sutured subboundaries".

Structure and Metamorphism

The main penetrative regional foliation is inhomogenously developed in the volcanic rocks, generally being restricted to pillow margins and the interstices, and to tuffaceous units within the flows. The foliation generally dips steeply with variations to both sides of vertical. The trend varies from predominantly northeastern in the west half of the map area to southwesterly in the east half of the map area. It is an L-S fabric associated with a steep stretching lineation, defined by chlorite and locally by fibrous actinolite. The flattening component of the foliation is shown by augen stuctures formed by epidote knots, including the epidotized cores of pillow lavas, and rare lapilli.

Deformed pillows are moderately to strongly elongated in the plane of the foliation, depending on the intensity of the deformation. Marten (1971a) suggested that the strain probably has K value of about 1 (Flinn, 1962), i.e., it approximates plane strain.

The regional foliation is interpreted to be axial planar to large-scale folds. No minor folds related to the main regional deformation were observed in the mafic volcanic rocks during the field component of this study. However, Sayeed (1970) reported folds that were apparently parasitic to a major structure in the Colchester area. Kennedy and DeGrace (1972) postulated that the area south of King's Point represents the inverted lower limb of a slightly overturned anticline that faces steeply upward to the southeast. Generally, however, major fold closures are not discernible within the Lushs Bight Group because of the lack of reliable geopetal structures and cleavage—bedding intersections. Boudins and pinch-and-swell structures developed during the main regional deformation are generally confined to chlorite-schist zones. The inhomogeneity of the deformation is reflected in belts of weakly deformed rocks grading into flanking zones of penetratively cleaved, strongly deformed rock characterized by chlorite schist.

Elongated or lenticular zones of coarse chlorite schist, tens of metres to hundreds of metres long and from a few metres to more than 100 m wide, are widely developed in the Lushs Bight Group. They have been interpreted as faults or shear zones, but in most cases there is no marked displacement of stratigraphy and no evidence marking planes of mechanical shear displacement (Kennedy and DeGrace, 1972). Fleming (1970) demonstrated that many of these zones are slightly sigmoidal in plan. They pass gradationally into the normal weakly deformed host rocks over a distance of one to tens of metres, depending on the width and intensity of the shear zone.

DeGrace (1971) described the schist-zone fabric in thin sections as follows:

> "...... the fabric is a strain-slip schistosity intersecting an earlier preferred mineral orientation fabric. Where the strain-slip schistosity is well developed (in the mineralized schist zones), the transposition of the preferred mineral orientation into the strain-slip bands is apparent. Both symmetrical and asymmetrical folding of the earlier fabric have been observed in thin-section ...... resulting in the development of minor folds in a few places. Magnetite is concentrated along the strain-slip planes.
>
> Where the strain-slip cleavage is weakly developed, it is seen as a series of epidote-magnetite bands approximately 1 mm apart (though not regularly spaced) which cross the weakly developed pre-existing foliation at angles of not more than about ten degrees and without apparently folding it ...... The sense of intersection of the two foliations is not clear because their relative orientations are variable. Similar fabric relations have been observed at a few localities outside the major schist zones where weakly developed strain-slip bands pass through rock which is otherwise typical of the regionally foliated Little Bay Head section."

The chlorite defines a foliation that is crenulated and kinked; delimbed fold noses are locally preserved. The chlorite forms augen around crystals and fragments of epidote, clinopyroxene and plagioclase. Bands, lenses and knots of carbonate (calcite), up to 15 percent and minor feldspar (± quartz) occur within the chlorite. Pyrite is ubiquitous. Crosscutting veinlets of carbonate and rare veinlets of quartz are locally present as in sericite.

Kennedy and DeGrace (1972) demonstrated that the foliation in the chlorite-schist zones, unlike the remainder of the Lushs Bight Group, is a composite fabric derived by folding and transposition of an earlier chlorite foliation. They further demonstrated that the chlorite-schist zones resulted from the superimposing of a regional deformation fabric on an older inhomogeneous fabric developed in shear belts. The regionally developed foliation in the Lushs Bight Group is thus the result of a second deformation that postdates the earlier fabric in the chlorite-schist zones.

At least four structural features, postdating the main regional deformation, affect the mafic volcanic rocks. Kennedy and DeGrace (1972) noted gently inclined north-dipping faults, paralleling the trend of the regional foliation and separating various units of the Lushs Bight Group in the Sprucy Brook and Ovals Pond area south of King's Point. They interpreted these to be thrust faults.

Crenulations having gently inclined axial surfaces fold the regional foliation and are best developed in the chlorite schist zones where they fold the composite fabric. These crenulations are folded by kinks—flexures and by steeply plunging, open folds having steeply dipping, axial planes that trend approximately north-northeast. The open folds do not affect the kinks—flexures and are interpreted to be contemporaneous with the kinks. These kinks—flexures and open folds are also best developed in the chlorite schist zones and fold the schist (Plate 16). The change in the trend of the regional foliation, schist zones and the above described thrust faults from northeast to southwest is interpreted to be a result of this phase of deformation.

Steeply inclined late faults are numerous in the Lushs Bight Group. There are three prominent alignments of post-folding faults. The general age sequence from oldest to youngest is a system trending about 045°, truncated by a 070° trending system and a less extensively developed system trending northwest (320°) (Plate 17). These age relationships appear to apply in most areas, but with local exceptions. The intersection of the 070°- and 045°-trending fault sets results in a diamond-shaped structural pattern that is reflected in the physiography. Narrow shear zones, breccia zones and carbonated breccia zones locally occupy the fault zones.

The Western Arm and Southwest Brook faults are examples of the 045°-trending fault system. The South Brook, Deer Pond, Davis Pond, Sullivan Pond and Gull Pond faults are examples of the 070°-trending fault system. The MacLean fault in the Halls Bay Head area is the best example of the northwest-trending faults.

Because of the lack of distinctive lithologic and stratigraphic markers within the Lushs Bight Group, the sense and amount of displacement on most of these faults is not easily discerned. Most of the northeast-trending faults are believed to have a major component of strike-slip

Plate 16. *Folding of the composite fabric in a chlorite schist, Lushs Bight Group.*

movement because of the large horizontal displacements documented in overlying sequences, straightness and lateral continuity (MacLean, 1947; Marten 1971 a, b). Kennedy and DeGrace (1972) speculated that these faults may locally have a component of dip-slip movement and suggested that some of the faults may have removed the axial zones of the major folds and thus the faults may be related to the folding. Both sets of northeast-trending faults appear to have a predominant sinistral-slip movement, although there are exceptions.

The northwest-trending structures are best developed in the east half of the map area, and are more prominent in the overlying sequences than in the Lushs Bight Group. Although they generally truncate and dextrally offset the northeast-trending structures, there are areas where they have apparently been displaced by northeast structures. Thus, there may have been two periods of movement.

Metamorphic assemblages in the mafic volcanic rocks are characterized by the extensive development of epidote, which in places completely replaces the cores of the pillow lavas (see Plate 9), as well as being present in veins, amygdules and fracture and cavity fillings. Albite—oligoclase, actinolite, chlorite and minor quartz constitute most of the remaining minerals in these rocks. This spilitic metamorphic assemblage is characteristic of the lower greenschist facies of metamorphism. The intensity of alteration is variable and, in general, decreases upward in the sequence. The mafic volcanic rocks at the top of the Lushs Bight Group are generally less strongly epidotized, have relatively more chlorite than epidote, and preserved plagioclase (as calcic as labradorite). The uppermost basalts are characteristically black and hematized.

Marten (1971a, b) informally referred to the two different types of alteration within the Lushs Bight Group as the 'main facies' and the 'black facies'. The "main facies" is green and grey-green epidotized mafic lavas, and is characteristic of the lower parts of the Lushs Bight Group, whereas the 'black facies' is grey-black to black, fresh to chloritic lava having epidote as veins and irregular patches, and is concentrated in the upper parts of the Lushs Bight Group, but has no formational status. Marten (1971b) suggested a correlation with the 'Whalesback type' and 'St. Patricks type' lava divisions, respectively, proposed by Papezik and Fleming (1967) in the Whalesback Mine area.

This alteration predated or accompanied the regional deformation and was not related to a structural event. It is interpreted to be a sub-seafloor alteration feature developed during the formation of the rocks (Spooner and Fyfe, 1973) (see Structure and Metamorphism section, page 32).

Contact Relationships

Mafic volcanic rocks of the Lushs Bight Group are generally in fault contact with sheeted diabase dykes, although gradational contacts can be seen along the west side of Little Bay. This gradation is marked by an increase in the number of dykes as the contact with the sheeted dykes is approached. The contact with the "overlying sequences" is also marked by faults and shear zones; however, the faults have been interpreted to modify the original conformable contacts (Kean, 1983, 1984). The contact area is marked by grey to black, hematized pillow lava and breccia with extensive interpillow and lensoidal, grey, green, white and red chert overlain by well-bedded chocolate-brown argillite and red chert of the 'overlying sequences'. The contact thus appears to be gradational. The sedimentary rocks are overlain by tuffaceous sandstone, argillite and chert and eventually pyroxene crystal tuff (see Overlying Sequences Section, page 24). Dykes of gabbro, diabase and porphyry are common.

The internal contact within the mafic volcanic rocks between unit L€Opd and L€Op is not defined because these subdivisions reflect the proportions of dykes and

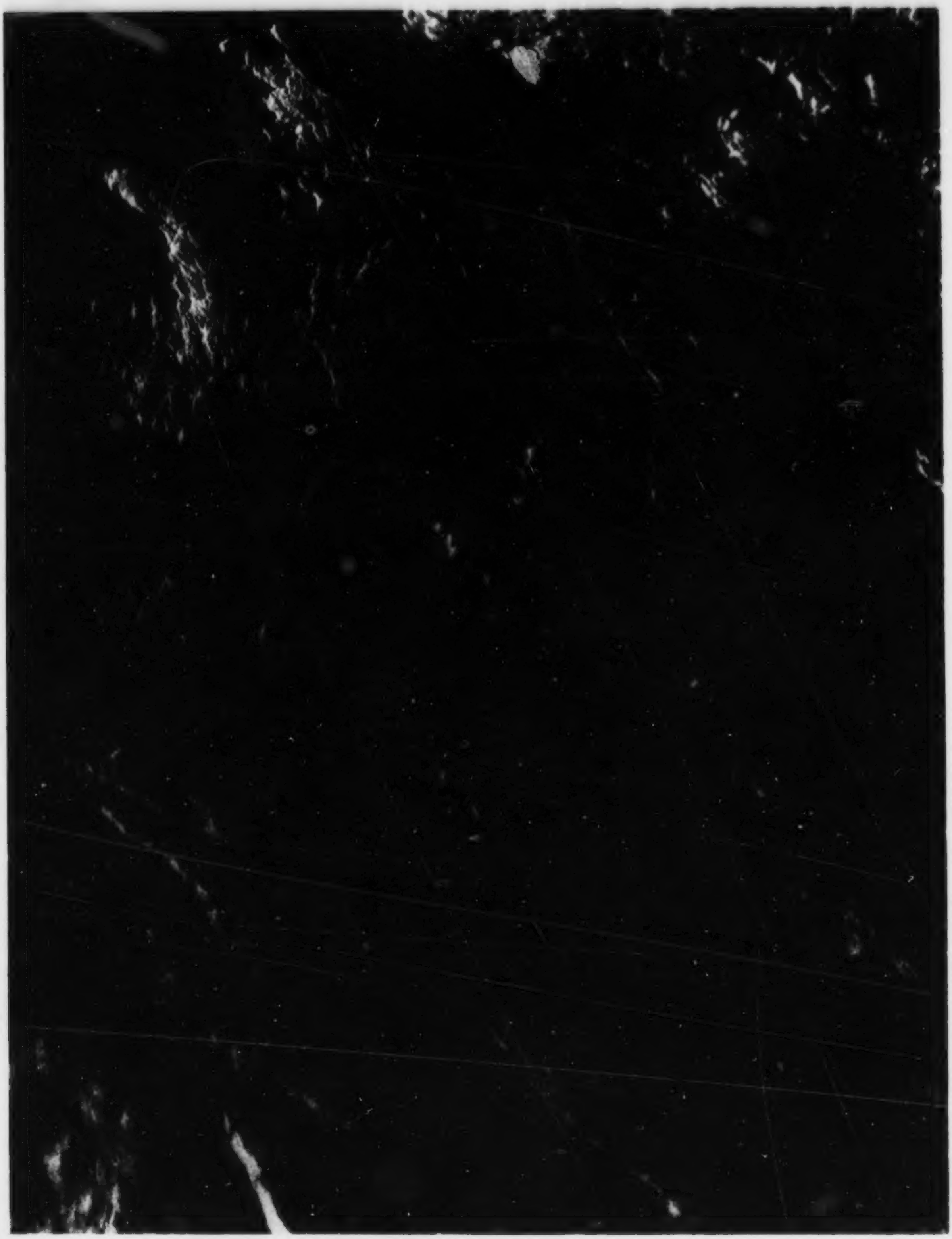


Plate 17. *Satellite image (CCRS Airborne SAR) showing the prominent linears affecting the Lushs Bight Group and surrounding rocks.*

lava. In well-preserved sections, a gradation from one to the other can be demonstrated. Breccia (subunit LЄOpx) and tuffaceous (subunit LЄOpt) units occur intercalated with, and as lateral facies to, the predominante pillow sequences. The contact between LЄOpb and underlying units is both gradational (e.g., north of Clam Pond) and sharp (e.g., north of Southern Arm) (Marten 1971a, b) but it has no stratigraphic significance as it only marks the upper limits of the epidote-dominated alteration.

Unit LЄOpa is a subdivision confined to a geographic area north and northeast of Springdale; all its contacts are fault bounded.

OVERLYING SEQUENCES

The Lushs Bight Group is overlain by pyroclastic and extrusive volcanic rocks of the Western Arm, Cutwell and Catchers Pond groups, and on Pilley's and Triton islands, by their equivalent. The contact relationships can be locally demonstrated to be conformable but are generally fault modified (Marten, 1971a, b; Kean 1983, 1984). The Western Arm and Cutwell groups were described by Marten (1971a, b) and Kean (1973) (see also O'Brien, 1975) and the Catchers Pond and Cutwell groups have been described by Szybinski (1995). The reader is referred to these workers for detailed information.

Many of the rocks underlying Pilley's and Triton islands that were previously assigned to the Lushs Bight Group have been reassigned to the overlying sequences (Kean 1983, 1984) and are tentatively correlated with the Cutwell and Western Arm groups. The rocks consist of interbedded pyroclastic rocks and pillow lava. The pyroclastic rocks consist of units of intermediate green breccia, lapilli tuff, and tuff that grade upward into well-bedded red argillite. The pyroclastic rocks underlie and are interbedded with the pillow lavas. The pillow lavas consist of large, bulbous and highly vesicular, black basalt and lesser amounts of feldspar-phyric green pillow andesite. The lower pillow basalts contain extensive interpillow red chert and breccias rich in red chert.

At both Fox Neck and Nickey's Nose, moderately hematized pillow basalts and interpillow red chert of the Lushs Bight Group are directly overlain by interbedded, chocolate-brown argillite and red chert containing lenses and beds of pyrite and black, magnetite-rich argillite (Plate 18). The chocolate-brown argillites and red chert units are overlain by well-bedded, green, yellow, grey and black argillite, siliceous argillite and tuff; these rocks in turn are overlain by pyroxene crystal tuff. Kean (1983, 1984) considered the crystal tuff to herald the beginning of explosive volcanic activity and it was thus regarded as the base of the overlying 'volcanic' complexes. Previous workers (e.g., Marten 1971a, b) included the bedded sedimentary rocks with the 'overlying sequences' such as the Western Arm Group, rather than the top of the Lushs Bight Group; this nonemclature is followed here.

Thinly bedded, aquagene tuff having rare lenses of grey magnetite-rich chert, red argillite, and magnetite-rich tuffs (Ot) and intercalated pillow basalt (Ov) in the Ketches Pond area, south of King's Point, have been previously included in the Lushs Bight Group (DeGrace, 1971). Papezik (1966) also reported magnetite-rich argillite (iron-formation) in that area and similar rocks, commonly associated with red argillite and chert, were found throughout this area. These rocks are lithologically unlike the Lushs Bight Group, the basalts associated with them are geochemically distinct, and their lower contact is generally marked by a regional airborne electromagnetic conductor. These rocks are probably equivalent to rocks at Fox Neck (Unit cOs) and Nickey's Nose (Unit wOs) and to the Skeleton Pond Tuff of the Western Arm Group and probably should be assigned to the Catchers Pond Group.

INTRUSIVE ROCKS

Introduction

There are numerous small, fine- to medium-grained, generally equigranular, but locally feldsparphyric, gabbro and diabase dykes, sills and small stocks intruding the Lushs Bight Group. They are mineralogically and chemically similar to the extrusive rocks and hence are discussed with the Lushs Bight Group.

Other plutonic rocks intrusive into the Lushs Bight Group include small gabbro and diabase dykes and sills, coarse hornblende gabbro of the Ordovician Brighton gabbro large-zoned complexes like the Colchester and Cooper's Cove plutons, and Siluro-Devonian porphyries and felsite dykes. Most of the felsic rocks, porphyries and late dykes intrude and/or feed the 'overlying sequences' and are adequately described in treatises on these rocks (see Marten, 1971a, b; Kean, 1973; O'Brien, 1975; Bostock, 1978). Here, rocks that are intrusive into the Lushs Bight Group only, including the Brighton gabbro, the Wellman's Cove, Bob Head, Colchester and the Cooper's Cove plutons will be discussed.

Brighton Gabbro

Definition and Distribution

The Brighton gabbro is an informal, but well-entrenched, term for very-coarse grained, hornblendite and a suite of progressively younger and more felsic phases

Plate 18. *Interbedded argillite and red chert overlying the Lushs Bight Group, Fox Neck.*

that underlie Brighton Tickle Islands, Cobbler Island, Cobbler Rocks, Big Island, Shoal Tickle Island, Great Tinker Island, Grassy Island and a number of small islands in the eastern part of the study area. It also underlies a small, northern point of Triton Island and a small sliver of a similar rock occurs on Pilley's Island. Espenshade (1937) considered the Brighton gabbro to be lithologically similar to the Wellman's Cove and Long Island plutons. Although earlier workers noted the diorites and hornblendites in the area, the name Brighton gabbro was first used by Strong (1972). The intrusion is named after the community of Brighton, located on Brighton Tickle Island. Hussey (1974) informally referred to the body as the Brighton gabbro complex, but the term is not extensively used. Excellent exposures of the gabbro occur along the coast of the island and in the roadcut at the north end of the Triton Island— Brighton Tickle Island causeway.

The Brighton gabbro forms an ovoid stock underlying an area of approximately 6 km^2. It is in fault contact along its southern boundary on Triton Island with pillow lava and pyroclastic rocks that may be correlative to parts of the Cutwell Group. Hornblende gabbros tentatively assigned to the Brighton gabbro intrude sheeted diabase dykes on the east coast of Pilley's Island.

Description

Hussey (1974) stated that, "the bulk of the complex is composed of a hornblende clinopyroxenite with lesser hornblendite. The pyroxenite shows cumulate textures and possibly, in places, a disrupted, steeply dipping primary cumulative banding or "bedding". It has been intruded by a range of textural and mineralogical variations of gabbro and diorite and later diorites, quartz diorites (trondhjemites) with associated intrusion breccias, trondhjemite veinlets, later granodioritic dykes, and finally diabase dykes and quartz-carbonate veins."

A brief description of rock types in the complex, in chronological order, adapted from Hussey (1974), is given below.

Serpentinized ultramafic rocks occur as fragments and blocks in the clinopyroxenite and gabbro. They occur predominantly on Big and Great Tickle islands and range in size from approximately 7 cm to 15 m across. Carbonate is locally extensively developed. Clinopyroxenite and hornblendite constitute the bulk of the intrusion. The proportions of clinopyroxene and hornblende are variable, and the two rock types grade into one another. The clinopyroxenite is green, medium to coarse grained and equigranular. The clinopyroxene is generally wholly or partially replaced by grey-green amphibole. The hornblendite is also green and generally coarser grained than the clinopyroxenite. Large hornblende crystals up to 10 cm in length poikilitically enclose pyroxene and magnetite. Acicular hornblende is often concentrated in zones growing from a sharply defined base of clinopyroxenite, imparting a layered appearance measuring from centimetres to metres. The lateral and vertical extent of this layering is not certain. "Layering" also occurs on a fine scale, defined by bands of pyroxene with plagioclase up to 1 cm thick alternating with plagioclase-rich bands that are several millimetres thick. Magnetite, especially in the clinopyroxenite, imparts a rough appearance to the rock. It normally constitutes about 5 percent of the rock, but locally comprises up to 40 percent, imparting a vague layering.

A characteristic feature of most of the hornblendite is an intense lineation of hornblende and plagioclase. The lineation trends northeast and generally plunges northeast, but southwest plunges occur locally. The lineation is generally perpendicular or at a high angle to the long axes of lenses, pods or pockets of hornblendite within the clinopyroxenite.

The gabbroic phase consists of medium-grained, glomeroporphyritic hornblende gabbro containing xenoliths of the previously mentioned rock types. Slightly younger hornblendite, gabbro, diorite, and locally anorthositic dykes, intrude the gabbro and contain xenoliths of all older rock types.

Fine- to medium-grained, equigranular, white to grey, diorite and quartz-diorite occur as dykes and large masses, which may represent plugs or products of a differentiated part of the magma chamber. These rocks generally contain a very high proportion of xenoliths resulting in spectacular intrusion breccias (Plate 19). Hussey (1974) classified the quartz-dioritic rocks as trondhjemites. Thin, white, aplitic veinlets, generally less than 1 cm in width intrude all the above rocks and are trondhjemitic in composition. Late granodioritic and diabase dykes are interpreted by Hussey (1974) to be related to the intrusion. The last event noted in the intrusion are east—west-trending quartz—carbonate veins up to 1 m thick. Disseminated chalcopyrite and molybdenite occur in the late granitoid veins.

Petrography

The serpentinized xenoliths consist essentially of serpentine and magnetite and partially preserved olivine and augite. Hussey (1974) suggested this rock originally may have been a harzburgite.

The clinopyroxenite and hornblendite consist of hornblende and augite in various proportions; hornblende content varies from 15 to 25 percent in the clinopyroxenite to 90 percent in the hornblendites. The hornblende occurs as anhedral, locally subhedral, crystals poikilitically enclosing both augite and magnetite. The hornblende and augite are variably alterated to actinolite. Magnetite is also a common constituent occurring both as scattered crystals and as concentrations constituting up to 40 percent of the rocks. Olivine is present in places, but it never constitutes more than 5 percent (Hussey, 1974). Plagioclase is a minor constituent, occurring interstitial to the mafic minerals.

Plate 19. *Intrusion breccia showing hornblendite intruded by quartz diorite, Brighton gabbro.*

Hussey (1974) estimated that the composition, although quite variable, of the gabbroic and dioritic phases and dykes averages 45 to 70 percent hornblende, 20 to 40 percent calcic plagioclase, and 10 to 15 percent augite and minor magnetite. Accessory minerals include sphene, zircon, and apatite (Hussey, 1974). In the dioritic rocks, the plagioclase content is greater than the hornblende content. In the porphyritic phases, the hornblende occurs both as stumpy, equidimensional phenocrysts and in the groundmass, it occurs with plagioclase and augite. In the equigranular phases, hornblende is more subhedral and acicular. Coarse biotite was reported from one dyke (Hussey, 1974). The mafic minerals are variably altered to actinolite and the augite, in most cases, is more extensively altered than the hornblende. The plagioclase is variably saussuritized and epidote and chlorite are also developed. Hussey (1974) reported thin veinlets of prehnite.

The diorites and quartz diorites are medium grained and consist of pyroxene, plagioclase, quartz and minor secondary biotite. Some quartz-rich varieties contain little or no mafic minerals. The pyroxene is generally altered to actinolite with the pyroxene cores preserved. Subhedral, variably saussuritized, crystals of oligoclase—andesine are strongly zoned and the accessory minerals include apatite and zircon.

Aplitic or trondhjemitic veins consist of about 80 percent strongly zoned, unaltered, subhedral sodic plagioclase, approximately 10 percent quartz and 10 percent subhedral to anhedral, green hornblende. The hornblende generally exhibits simple twinning.

Late granodioritic dykes are composed of quartz (approximately 40 percent), strongly zoned, subhedral oligoclase (approximately 35 percent) with altered cores, perthite (approximately 20 percent) and microcline (approximately 5 percent). Subhedral to anhedral, green hornblende constitutes up to 5 percent of the rock. Accessory sphene and opaques are present. The late diabase dykes consist of epidotized plagioclase phenocrysts in a holocrystalline groundmass of plagioclase microlites; quartz and carbonate veinlets are numerous (Hussey, 1974).

Structure and Metamorphism

There is no penetrative fabric developed in the Brighton gabbro. The hornblendites have a lineation defined by hornblende and plagioclase, which was interpreted by Hussey (1974) to be a growth feature at the time of emplacement and not related to later deformation. The intrusion is metamorphosed to a lower greenschist-facies assemblage characterized by actinolite, minor chlorite and epidote. This metamorphic facies is characteristic of the surrounding rocks.

Contact Relationships and Age

Pillow lavas and tuffs along the north shore of Triton Island were equated with the Lushs Bight Group, and gabbro and diabase dykes intrusive into them were correlated with the Brighton gabbro (Hussey, 1974). However, Kean (1982, 1983) demonstrated that volcanic rocks on Triton Island are not a part of the Lushs Bight Group, but equivalent to the overlying Ordovician age Cutwell Group. He also interpreted the Brighton gabbro to be in fault contact with the volcanic rocks and found no evidence of contact metamorphism. Its relationship to the external fabric developed in the volcanic rocks has not been defined because of this faulting. On the east side of Pilley's Island, rocks similar to the Brighton gabbro intrude sheeted diabase dykes correlated with the Lushs Bight Group.

Stukas and Reynolds (1974) reported an ^{40}Ar—^{39}Ar age of 495 ± 5 Ma on hornblende for the Brighton gabbro. This Early Ordovician age correspond very well to the Early Ordovician - Cambrian age postulated for the Lushs Bight Group. Recent age dating of the complex gave ^{40}Ar—^{39}Ar ages of 473 ± 2.2, 473 ± 2.4 and 475 ± 2.6 Ma and a U—Pb zircon age of 478.5 ± 4.5 Ma (Szybinski, 1995).

Colchester Pluton

Definition and Distribution

The name Colchester Pluton was coined by Sayeed (1970) for a zoned plutonic complex located near Colchester Pond in the Southwest Arm area. It is elliptical and underlies an area of approximately 10 km^2 extending northeast from Colchester Pond to Saunders Brook between Southwest Arm (Green Bay) and West Brook. MacLean (1947) referred to this pluton as the Colchester granodiorite—quartz diorite. The pluton is intrusive into the Lushs Bight Group, although its western and eastern contacts are loci of extensive shearing related to movement on the Green Bay and Western Arm faults, respectively.

Sayeed (1970) divided the pluton into i) a marginal dioritic phase, ii) a transitional quartz-dioritic phase, and iii) a central or core granodioritic phase. The contacts between these different phases are generally defined by the quartz, K-feldspar and mafic mineral content. They are, therefore, gradational and not always well defined. The brief description below of each phase or zone is adapted from Sayeed (1970).

Description

Marginal Phase. This peripheral phase, which is in contact with the Lushs Bight Group, consists of greenish grey to green, medium to coarse-grained, diorite—gabbro (meladiorite of Sayeed, 1970) and minor quartz diorite. The rocks are generally equigranular with abundant lenticular inclusions of basic volcanic rocks. An alignment of plagioclase and mafic minerals locally defines a primary fabric. He also reported an alignment of the basic inclusions; however, it is not clear whether this is a primary flow or tectonic feature. Diabase dykes are minor to extensive.

Transitional Phase. This phase is intermediate in position between the marginal and central zones and varies in outcrop width from 150 to 1200 m. The phase consists of dark to light green, medium-grained quartz diorite and granodiorite. It appears to grade inward from the marginal phase through an increase in the quartz and a decrease in mafic minerals. Small basic inclusions are less abundant than that in the marginal phase, but large roof pendants are present northeast of Colchester Pond (Sayeed, 1970).

Central Phase. The core of the Colchester Pluton is occupied by a quartz-rich, leucocratic granodiorite. It is gradational from the transitional zone through an increase in quartz, a decrease in, or absence of, mafic minerals and the appearance of potash feldspar. The rocks vary from light green to pinkish green, are medium grained, equigranular and generally exhibit granophyric textures. The rock is almost devoid of basic inclusions.

Petrography

Marginal Phase. This phase contains anhedral to subhedral, locally euhedral, plagioclase, that is variably saussuritized, and in some places, completely altered to epidote, calcite and sericite; it has an average composition of An_{38} (andesine) (Sayeed, 1970). He also reported the occurrence of uralitized hornblende and clinopyroxene; common secondary minerals are actinolite, chlorite and other mafic minerals. Anhedral quartz occurs interstitial to the plagioclase and mafic minerals. Chlorite, epidote, carbonate, opaques and sphene also occur as accessories in the groundmass; chlorite defines a weak foliation.

Transitional Phase. This phase consists of subhedral to euhedral, andesine plagioclase (An_{32}) that is variably saussuritized. Hornblende and minor clinopyroxene, which are variably uralitized and altered to actinolite, constitute about 25 percent of the rock. Quartz occurs interstitially, and chlorite and quartz define the foliation.

Central Phase. The core of the pluton has a dominant mineralogy of plagioclase, quartz and potash feldspar, and is characterized by a granophyric texture. Epidote, zoisite, chlorite, carbonate, magnetite, sphene and sericite occur as secondary and accessory minerals. Quartz occurs as subhedral to euhedral crystals and displays undulatory extinction and cataclastic textures (Sayeed, 1970). Oligoclase (An_{28}) occurs as subhedral to euhedral, twinned crystals that display oscillatory zoning and are locally moderately saurssuritized. Hornblende is rare and chlorite is the dominant mafic mineral.

Structure and Metamorphism

The Colchester Pluton has an inhomogeneously developed foliation, which is better developed in the fine- to medium-grained rocks than in the coarser varieties. The foliation is steeply dipping, generally to the southeast, and the strike locally varies to southeasterly from the regional northeasterly trend. This change is interpreted to reflect a later phase of deformation. The foliation is defined by elongate and flattened quartz, exhibiting undulatory extinction and sutured and subgrain boundaries, and by chlorite. The mafic minerals form augen around which the chlorites are deformed.

Sayeed (1970) concluded that the foliation in the Colchester Pluton is the same as that developed in the country rocks requiring the pluton to have been intruded prior to deformation. He speculated that the Colchester Pluton acted as a competent block around which the Lushs Bight Group was deformed.

Shearing and fault zones are locally developed throughout the pluton, particularly along the eastern and western margin where the Western Arm and Green Bay faults respectively form the boundaries. The pluton is metamorphosed in the lower greenschist facies. Epidote, calcite, sericite, actinolite and chlorite are generally present.

Contact Relationships and Age

The Colchester Pluton intrudes the Lushs Bight Group. The contact is sharp and crosscutting relationships are well established. However, no contact metamorphic aureole was noted. An emplacement flow fabric is developed peripheral to the contacts and lenticular inclusions of the country rock are abundant. The long axes of these inclusions are in places oriented parallel to the tectonic fabric. Sayeed (1970) interpreted the pluton to be Ordovician in age because of i) the spatial association of this and similar plutons with Lower Ordovician volcanic rocks, and ii) its pre-deformation emplacement age. Szybinski (1995) reported an U—Pb zircon age on quartz diorite as 465.6 ± 2.5 Ma.

Cooper's Cove Pluton

Definition and Distribution

Sayeed (1970) used the name Cooper's Cove Pluton for a zoned intrusion exposed near Cooper's Cove, Southwest Arm. Neale and Nash (1963) included it as part of the Burlington Granodiorite. The name Cooper's Cove Pluton is formally proposed herein. It is elongated northeast—southwest and extends from Cooper's Cove in the north to Manful Point in the south. It underlies an area of approximately 5 km^2.

The Cooper's Cove Pluton intrudes the Lushs Bight Group along its eastern and southern boundary. Its northern boundary is defined by the Cooper's Cove fault and its western boundary is marked by Southwest Arm and thus probably the Green Bay fault.

Sayeed (1970) divided the pluton into i) a marginal or peripheral phase of diorite and meladiorite, and ii) a central phase or core of quartz monzonite—adamellite. The marginal phase is the areally most extensive and is intruded by the central phase. Fine-grained diabase and pyroxene porphyry dykes intrude the pluton.

Description

Marginal Phase. This phase forms the peripheral and larger part of the pluton. It consists of an equigranular, medium- to coarse-grained, green diorite and gabbro phase, and a fine-grained generally dioritic phase. Xenoliths of the host mafic volcanic rocks occur in the contact zone. A number of ultramafic pods are present within the marginal phase. They may represent xenoliths unrelated to the intrusion (see Lushs Bight Group Section, page 9); alternatively, they may represent an earlier phase of the pluton. A weak foliation is locally developed.

Central Phase. This phase constitutes the core of the pluton. Dykes and veins of it intrude the marginal phase and inclusions of diorite and gabbro occur within it. The central phase consists of a medium- to coarse-grained, equigranular with local porphyritic phases, biotite granitoid rocks. They generally weather pinkish-grey and are greyish on fresh surfaces. Sayeed (1970) classified these rocks as quartz monzonite and adamellite according to the classification of Johannson (1939). However, by the Streckeisen (1976) classification, they are granitic and granodioritic. Locally, they contain a well-developed foliation defined by quartz and biotite.

Petrography

Marginal Phase. The dominant feldspars in the gabbro—diorite rocks of the marginal phase are albite and Carlsbad—Albite twinned andesine. The subhedral to euhedral andesine crystals are relatively fresh and locally display bent twin lamellae. Hornblende and actinolite (after pyroxene?) are the main mafic minerals, although chlorite is present locally as an alteration of the hornblende. Quartz occurs as interstitial crystals to the amphibole and plagioclase.

Central Phase. This phase consists of plagioclase, K-feldspar, quartz, biotite, and hornblende. Plagioclase is the most common constituent, occuring as tabular, zoned crystals of about An_{35} composition (Sayeed, 1970). Both normal and oscillatory zoning are present and the zones have undergone different degrees of saussuritization. Quartz is the next most common constituent occuring as anhedral crystals having undulatory extinction, which are elongated in the foliation plane. Recrystallization, subgrain boundaries and sutured boundaries characterize the quartz crystals. Potassium feldspar occurs as small to large anhedral to euhedral crystals of microcline and microperthite.

Biotite is more abundant than hornblende and occurs both as isolated, ragged flakes and as thick aggregates and defines a weak foliation. The hornblende and biotite are variably altered to chlorite. Sphene, apatite and opaque minerals are the accessory phases.

Structure and Metamorphism

The Cooper's Cove Pluton contains an inhomogenously developed foliation defined by elongate quartz crystals and biotite. This foliation generally trends southeast, dips steeply, generally to the north; however, Sayeed (1970) concluded that the foliation is the same as that developed in the country rocks. Shearing and faulting are locally developed and generally trend northwest—southeast.

The pluton has been metamorphosed in the greenschist facies.

Contact Relationships and Age

The pluton intrudes the Lushs Bight Group. The contact is ill-defined because of lack of outcrop, but dykes of gabbro and diorite similar to the pluton cut the Lushs Bight Group and inclusions of mafic volcanic rocks are present in the contact area. The intrusion was pre-tectonic and lithologically resembles the Colchester Pluton (Sayeed, 1970). He also proposed a genetic link with the Lushs Bight Group based on geochemistry; the pluton was thus considered Ordovician in age.

Wellman's Cove Pluton

Definition and Distribution

This name has been informally used for a small quartz-diorite to gabbro body exposed near Wellman's Cove, Sunday Cove Island (Dean, 1977). Espenshade (1937) referred to this body as the Wellmans Cove diorite. Kean (1971) referred to it as the Sunday Cove Island intrusive complex. The name Wellman's Cove Pluton is formally proposed herein.

The pluton underlies an area of approximately 0.5 km^2 immediately to the south of, and bordering on, Wellman's Cove. However, Kean (1971) described the body as a stock, which based on aeromagnetic evidence also underlies an area to the northwest under the sea. It intrudes the Lushs Bight Group although contacts are generally faulted and sheared. He also described the rock types in the body and the following descriptions are adapted from that report.

Description

The pluton is not uniform in composition, mineralogy or texture. Medium- to coarse-grained, equigranular, black and white speckled to green quartz diorite is the most common rock type, although darker colour (i.e., more mafic) and coarser grained, gabbroic phases are present locally. In places, zones of coarse-grained, tabular amphibole, which locally has pyroxene outlines, appear to constitute a separate phase, and angular xenoliths of similar rocks are also present. Xenoliths, which are present throughout the pluton, are extensively developed near the southwest contact. Coarse-grained gabbro, diabase, brown-weathering ultramafic (?) and mafic volcanic rocks constitute most of the xenoliths. The xenoliths are generally angular and rectangular, although locally they are subrounded to round, particularly the brown-weathering ultramafic-like inclusions. The pluton is intruded by dykes of diabase, feldsparphyric gabbro, aplite and red, rhyolitic quartz-porphyry.

Petrography

The darker coloured, more basic phases consist mainly of plagioclase, augite and hornblende. It has a normative An content of 35 to 60. The variably saussuritized plagioclase crystals are generally subhedral to euhedral and display albite and combined Carlsbad—Albite twins. The margins and cores of the augitic pyroxene crystals have been replaced by green-brown hornblende along cleavage planes; exsolved magnetite is present locally along the hornblende cleavage. Hornblende also occurs poikilitically enclosing plagioclase and quartz and is usually altered to chlorite, in particular around its margins.

Magnetite and antigorite occur in aggregates outlining the shape and internal fractures of the olivine crystals that they replaced. Pure iddingsite rims to these aggregates were also noted (Kean, 1971). No olivine crystals were seen. Accessory minerals include sphene, pyrite, apatite and magnetite; quartz occurs as a secondary mineral.

The more leucocratic rocks are dioritic to quartz dioritic. These rocks consist of plagioclase, hornblende and quartz displaying subophitic texture. The plagioclase occurs as variably saussuritized euhedral crystals, both as microphenocrysts and in the groundmass. The plagioclase has a composition of An_{30-35} and display albite and combined Carlsbad—Albite twins. The brown-green hornblende is slightly altered to chlorite and minor actinolite—tremolite occurs along its margins. It is not known if the hornblende is after pyroxene, although in places the hornblende appears to be overgrowing cloudy and dusty fine-grained mineral aggregates that may have been pyroxene. Quartz, up to 10 percent, occurs in the groundness both as a secondary mineral and as a primary interstitial mineral. Sphene, pyrite and opaques occur as accessory minerals.

Structure and Metamorphism

There is no penetrative foliation developed in the Wellman's Cove Pluton and its relationship to the fabric in the country rocks is not known because of faulting and shearing along the contacts. Two narrow shear zones containing carbonate, carbonate veins and sheared chloritic fragments cut the pluton.

The secondary mineral assemblage of epidote calcite, chlorite and actinolite—tremolite is indicative of the lower greenschist-metamorphic facies.

Contact Relationships and Age

The contact with the Lushs Bight Group is faulted and/or not exposed. However, the pluton contains xenoliths of mafic volcanic rock, and hornfels have been noted locally in the area (Kean, 1971). Therefore, the pluton is interpreted to be intrusive into the Lushs Bight Group.

This pluton has been correlated with the Long Island Pluton (Espenshade, 1987), which intrudes the Middle Ordovician Long Tickle Formation (Kean, 1973). Espenshade (*op. cit.*) also correlated it with the Brighton gabbro.

Bob Head Pluton

Definition and Distribution

The Bob Head Pluton is a name used by Dean (1977) and formally proposed here for a small intrusive on the north side of Halls Bay, immediately south of Bob Head. It underlies an area of < 0.5 km^2 but probably forms a circular body that extends under the sea to the south. It consists of gabbro and a late phase of diorite.

Description

The Bob Head Pluton consists of equigranular, mafic-rich, melanocratic gabbro, with a grain size varying from fine to coarse. Local coarser, pegmatitic-like patches or zones occurring on outcrop scale within the medium- to fine-grained varieties. Intrusion breccias, consisting of coarse-grained gabbro fragments in medium-grained gabbro, are locally developed. Veins, veinlets, and irregular patches of more leucocratic, dioritic phases cut and occur within the melanocratic rocks.

Dykes of diabase, andesite and pinkish-brown, aphanitic felsite intrude the above described rocks. The felsite dykes are abundant in the country rocks and appear to be spatially related to the pluton.

Petrography

The rocks of the Bob Head Pluton essentially consist of hornblende and plagioclase. The hornblende is green and pleochroic, generally displaying simple twinning and poikilitically encloses aggregates of alteration minerals, in particular, carbonate. Plagioclase occurs interstitially to the hornblende and is generally completely saussuritized.

Structure and Metamorphism

The Bob Head Pluton has no discernible penetrative foliation; however, associated felsite dykes are fractured and broken and its relationship to the regional foliation developed in the Lushs Bight Group is not known. The pluton is characterized by a lower greenschist-metamorphic assemblage.

Contact Relationships and Age

The contact with the Lushs Bight Group is not exposed. Xenoliths of the country rock are present in the pinkish-red felsites that intrude the Lushs Bight Group and Bob Head Pluton. These dykes appear to be more extensively developed near the Bob Head Pluton. The age of the pluton is not known but it is considered lithologically similar to the Wellman's Cove Pluton and thus probably of the same age.

Younger Dykes

Younger dykes intruding the Lushs Bight Group consist of fresh diabase, quartz-feldspar rhyolite porphyry, grey felsite and feldspar-, amphibole-, pyroxene-porphyries. Sayeed (1970) recognized two suites of diabase dykes; a) an older, slightly altered set having a weak to moderately developed fabric, and b) an unaltered, undeformed set. The older suite is probably related to the Lushs Bight Group. The younger suite may be related to the overlying volcanic sequences or part of the younger Devonian intrusive event.

The unaltered and undeformed dark grey to black, fine- to medium-grained diabase dykes consist of fresh to saussuritized plagioclase of up to An_{30} compositions. Clinopyroxene occurs subophitically to the plagioclase. Sayeed (1970) also reported euhedral to subhedral olivine altered to serpentine in the dykes around the Colchester area. Magnetite, ilmenite and pyrite occur as accessory minerals and chlorite is also present.

The felsic porphyritic rocks consist of quartz, feldspar and quartz-feldspar varieties. They vary in colour from white to green to pinkish-red. Red aplitic to granitic and alaksitic intrusions are present locally. They are intruded by diabase dykes. The felsic dykes are generally interpreted to be related to the overlying Catchers Pond and Springdale groups.

Feldspar, amphibole and feldspar-amphibole porphyry dykes and lesser, pyroxene and pyroxene-feldspar porphyries are abundant locally, e.g., in the Whalesback area. The dykes vary in width from several centimetres to several metres and trend northwest or slightly east of north. They are probably camptomitic lamprophyres. Fleming (1970) reported that some of the dykes, particularly within the shear zones, are boudinaged and thus predeformation. However, Sayeed (1970) considered them to be the latest intrusive event. Kanehira and Bachinski (1968) also noted that the porphyry dykes were unsheared; however, in places they are boudinaged.

STRUCTURE AND METAMORPHISM

STRUCTURE

The area contains a single regional foliation that is inhomogeneously developed. Within the Lushs Bight Group the foliation is restricted to tuffaceous units, pillow margins and their interstices. The intensity of the foliation decreases upward, and is weak to absent in the rocks overlying the Lushs Bight Group. It is steeply dipping but may vary to either side of vertical. The trend of the foliation, like the trend of stratigraphic units, varies from predominantly northeasterly in the west to southeasterly in the east, reflecting a late-stage open-folding about a north—south axis. It usually is an L-S fabric associated with a steep stretching lineation and is defined by fine-grained chlorite and fibrous amphibole.

The regionally developed foliation is interpreted to be axial-planar to large-scale folds. The combination of local facing directions and the distribution of stratigraphic units, allows the postulation of major structures although the lack of reliable geopetal structures and structural data makes the recognition of such structures difficult. Marten (1971a, b), on the basis of cleavage—bedding relationships, identified the southwestern limb and axial region of a large-scale, northeast-plunging syncline in the Western Arm Group. Kennedy and DeGrace (1971) recognized the inverted lower limb of a slightly overturned, south-facing anticline to the south of King's Point. The predominantly south-facing sequences on Long Island and southwesterly on Little Bay Island have been documented by Kean (1973) and O'Brien (1975) (Figure 5). Despite the complications due to later folding and faulting, it can be deduced that the area was folded into a number of originally northeast-trending, antiforms and synforms.

Shallow northeast- to southeast-plunging folds having steep, locally overturned, northerly limbs and flat-lying, shallowly south-dipping limbs are well developed in the rocks on Pilley's and Triton islands (Plate 20). These "monoclinal type" folds have been interpreted to be part of an antiformal stack related to north-directed thrusting and folding (Szybinski, 1988). Later crenulations, kinks and open folds occur in the Lushs Bight Group and in the overlying sequences.

The Lushs Bight Group is characterized by the development of chlorite-schist zones that are parallel to subparallel to the regional trends. The chlorite-schist zones contain a composite fabric resulting from the superimposition of a regionally developed fabric on an older inhomogeneously developed fabric, possibly in a shear zone (Kennedy and DeGrace, 1972). This early fabric is apparently restricted to the chlorite-schist zones within the Lushs Bight Group. It is suggested that the early fabric may represent early fault—shear zones developed in the rocks at or near their site of deposition. In many cases, these early zones of shearing and faulting provide zones of weakness along which hydrothermal fluids migrated. Subsequent deformations transposed the earlier structures into the regional trend. (See Economic Geology section, page 65)

Marten (1971 a, b) recognized a series of northeast-trending faults within the Western Arm Group, with apparent sinistral displacement, up to approximately 2400 m. The faults are subparallel to the regional cleavage. He noted that the cleavage intensifies in the fault zones, such that the mafic rocks have been metamorphosed to chlorite schist. He interpreted the faults as possibly being related to the folding, i.e., slides. The faults or slides penetrate to higher stratigraphic levels within the Western Arm Group than does the cleavage and are probably related to or the same age as, gently inclined, north-dipping, thrust faults within the Lushs Bight Group that parallel the regional foliation (see Kennedy and DeGrace, 1972). Some of the chlorite-schist zones within the Lushs Bight Group may have a similar origin.

As stated earlier, there are at least three directions of post-folding faults. The age sequence from oldest to youngest is: i) 045°-trending fault system, ii) 070°-trending fault system, and iii) northwest-trending (320°) fault system. Displacement of stratigraphic units and linears indicate that both sets of northeast-trending fault systems have a component of sinistral strike-slip movement (e.g., the ones south of Western Arm); however, many workers have suggested a considerable regional dextral component. For example, a dextral wrench component of more than 1800 m is inferred for the Southwest Brook fault based on the displacement of the Western Arm Group (MacLean, 1947). Marten, (1971a, b) also suggested dextral movement for the Western Arm fault based on the sense of rotation of bedding and cleavage in the Harry's Harbour area. The Green Bay fault was interpreted to have a dextral displacement of about 22 km; however, Jenner and Szybinski (1987) proposed a sinistral displacement.

The relationship of the 070°-trending Gull Pond and Sullivan Pond faults and the system of faults in the Davis Pond area to the east—west-trending, bounding Lobster Cove Fault is ambiguous. MacLean (1947) and Neale and Nash (1963) interpreted the Davis Pond fault system to dextrally offset the Lobster Cove Fault by about 4 km,

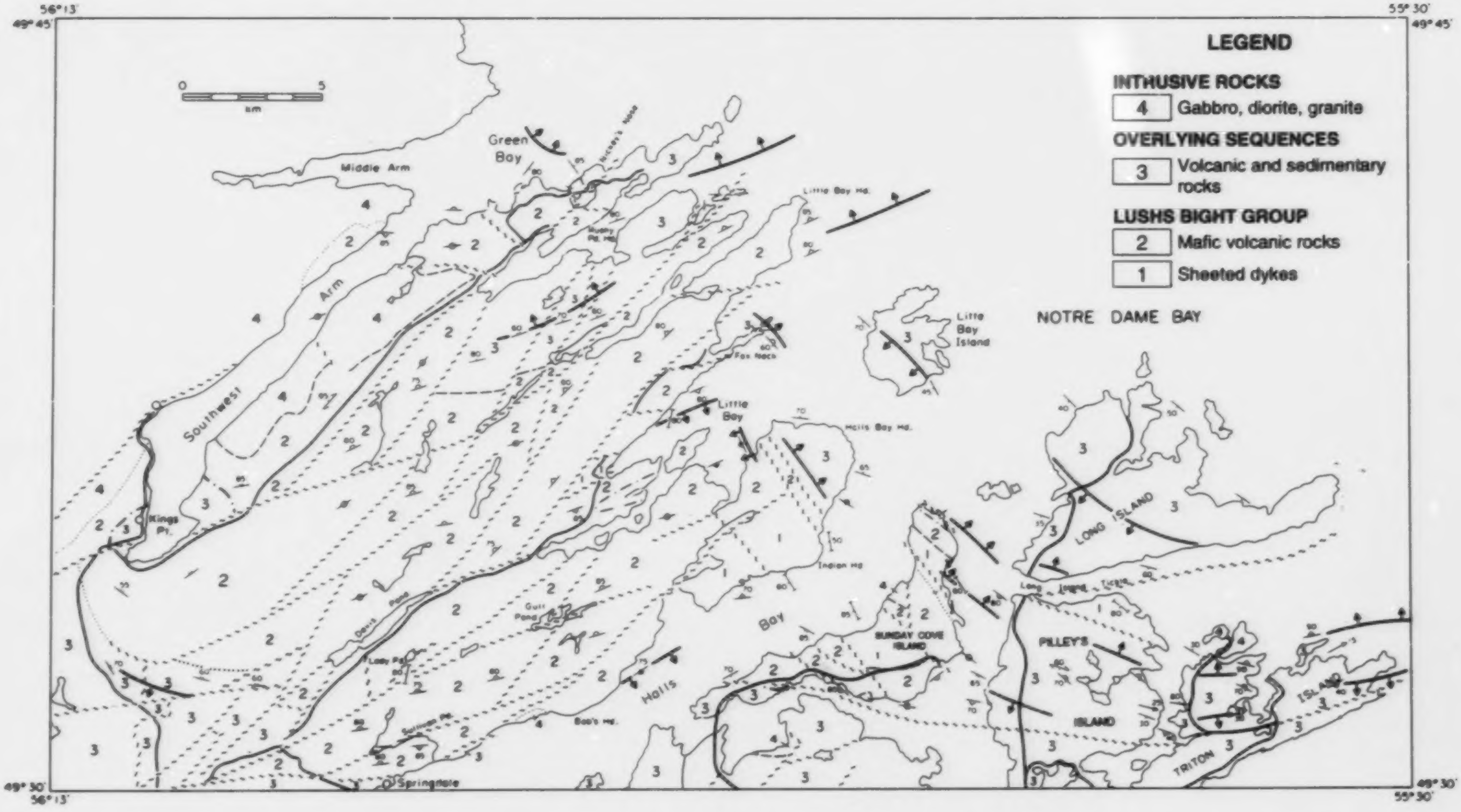

56°13'
49°45'
55°30'
49°45'
49°30'
56°13'
49°30'
55°30'
LEGEND
INTHUSIVE ROCKS
4 Gabbro, diorite, granite
OVERLYING SEQUENCES
3 Volcanic and sedimentary rocks
LUSHS BIGHT GROUP
2 Mafic volcanic rocks
1 Sheeted dykes
0
5
km
NOTRE DAME BAY
Green Bay
Middle Arm
Southwest Arm
Kings Pt.
Little Bay Hd.
Little Bay Island
Fox Neck
Little Bay
Halls Bay Hd.
Indian Hd
Halls Bay
Gull Pond
Lady Pd.
Springdale
Bob's Hd.
SUNDAY COVE ISLAND
LONG ISLAND
Long Island Tickle
PILLEY'S ISLAND
TRITON

Figure 5. *Regional facing direction of rocks in the Springdale Peninsula area.*

Plate 20. *Monoclinal fold in an antiformal stack, 'Overlying Sequence', Triton Island.*

based on the outcrop pattern of the Springdale Group. However, mapping by Jenner and Szybinski (1987) and Coyle and Strong (1986) indicate that the Lobster Cove Fault truncates these northeast-trending structures. A similar interpretation is made from the accompanying maps to this report. Szybinski (1988) and Szybinski *et al.* (1991) considered the east—west-trending part of the Lobster Cove Fault to be a strike-slip wrench fault with a dextral movement; however, leading and trailing parts of the fault, as in the Springdale area, display evidence for oblique strike-slip and easterly directed thrusting.

Jenner and Szybinski (1987) interpreted the east—west-trending fault in the Ketches Pond area (Catchers Pond fault) to be a thrust fault juxtaposing the stratigraphically lower rocks to the north against the younger rocks of the Catchers Pond and Springdale groups. The map-pattern shows this fault truncating the northeast-trending strike-slip faults. This thrusting is then younger than the thrust faulting described by Kennedy and DeGrace (1972) in the area immediately to the north. It is probably the same age as the Lobster Cove Fault.

Szybinski (1988) concluded, as previously postulated, that the northwest-trending MacLean and the east—west-trending Long Tickle faults are thrusts, characterized by well-developed schistosities and downdip mineral lineations. He interpreted the Lushs Bight Group to have moved northeasterly over the younger 'overlying sequence' rocks on the south-dipping MacLean fault. The Long Tickle fault is essentially vertically dipping and is interpreted as a steepened or folded thrust (Dean and Strong, 1977). This fault is probably a deep-seated structure as it brings ultramafic rocks against the Cutwell Group (Kean, 1973; Szybinski, 1988). Szybinski (*op. cit.*) interpreted these to be early faults, probably related to folding, in particular to antiformal stack structures.

METAMORPHISM

The main period of metamorphism in the Lushs Bight Group predated the regional deformation and is characterized by extensive epidotization. It is most strongly developed in the pillow lavas and generally decreases in intensity upward. Actinolite is generally more abundant in the 'dense' sheeted-dyke complexes. In places, the top of the Lushs Bight Group is less altered and generally more chloritic. Metamorphism, related to the regional deformation, was mainly limited to growth of chlorite and fibrous amphibole along the foliation.

The "main facies" and overlying "black facies" recognized by Marten (1971a, b) represent metamorphism and not stratigraphic divisions. The "main facies" consists of green and grey-green, epidotized mafic lavas whereas the "black facies" is composed of dark-grey to black, chloritic and fresh lava with epidote as veins and irregular patches. Hematization is common, and the rocks are locally magnetic.

The contact between the two facies is irregular and can be either gradational or sharp; it is not related to the direction or intensity of cleavage. Secondary minerals, such as epidote, are deformed and cleavage-defining minerals, such as chlorite and fibrous hornblende, form augen around the epidote grains. Marten (1971a, b) considered the "main facies" alteration to be a sub-seafloor feature, rather than deformation related.

Studies of metamorphism in ophiolites (e.g., Spooner and Fyfe, 1973) indicate that intense alteration and metamorphism of lower pillow lava units prior to deposition of upper pillow lava units is a common phenomenon. This is postulated to result from sub-seafloor hydrothermal metamorphism at active spreading ridges. The alteration facies developed in the Lushs Bight Group is thus interpreted to be a sub-seafloor alteration feature developed during the formation of the group.

Recent studies of alteration and metamorphism in seafloor basalts and the role of seawater convected through them have emphasized the importance of the ratio of the volume of seawater to the volume of rock permeated (e.g., Mottl and Seyfried, 1980; Mottl, 1983; Bischoff and Dickson, 1975; Hajash, 1975; Seyfried and Mottl, 1982).

Furthermore, experiments and studies of ocean-floor basalts have shown consistent relationships among the bulk chemistry of the altered rocks and their secondary mineralogy, mineral abundances and mineral compositions, especially for chlorite. The relationships have been interpreted in terms of the distribution of alteration with respect to time, temperature and most importantly seawater to rock ratios (Mottl, 1983). Downwelling or recharge flow is diffused over a large area, thus there is a low seawater to rock ratio, whereas upwelling or discharge flow is usually concentrated and focused along faults, fractures and permeable zones resulting in a high seawater to rock ratio. Basalts altered in the descending limb of a convection system, i.e., at low to moderate seawater to rock ratios, would be characterized by an assemblage of chlorite—albite—epidote—actinolite—quartz at 300°C (Figure 6). This is the spilitic background alteration assemblage present in most of the volcanic rocks of the Lushs Bight Group. The sheeted-dyke complexes contain more actinolite than the basalts; this probably reflects a lower seawater to rock ratio due to their being less porous and permeable. The epidote—albite—actinolite—(quartz) dominated alteration of the Lushs Bight Group is thus interpreted to result from seafloor alteration by recharge flow at the time of formation. The areas within the Lushs Bight Group characterized by chlorite—quartz-sulphide assemblages are interpreted to represent areas of high seawater to rock ratios, i.e., upwelling flow.

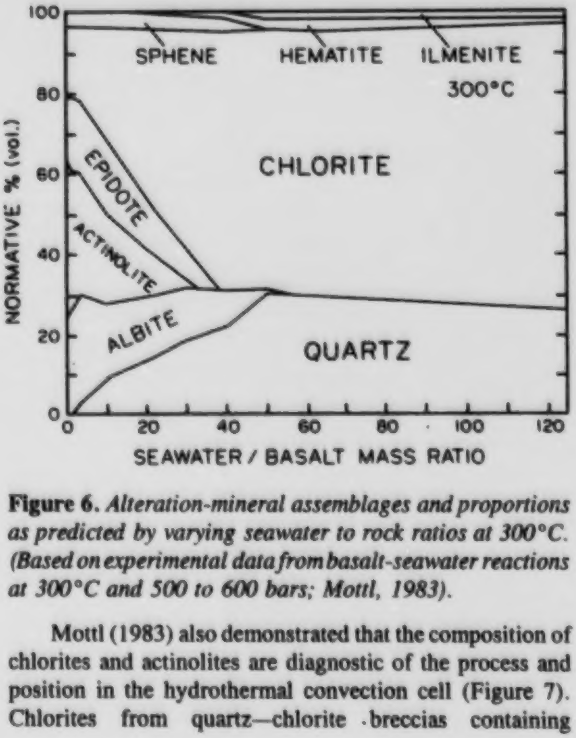


Figure 6. *Alteration-mineral assemblages and proportions as predicted by varying seawater to rock ratios at 300°C. (Based on experimental data from basalt-seawater reactions at 300°C and 500 to 600 bars; Mottl, 1983).*

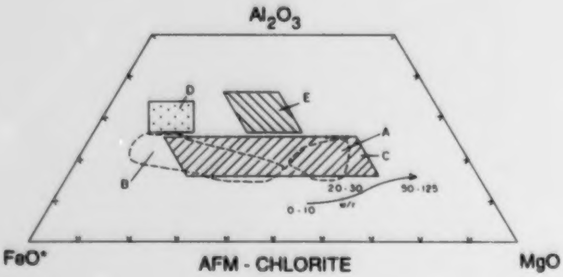


Figure 7. *Composition of chlorites from seafloor greenstones including typical metabasalt and chlorite-quartz metabasalt (field A) compared with chlorite composition from chlorite—quartz—sulphide-rich breccias (field B) in an upwelling zone (Mottl, 1983). Field C represents the range of composition from Mg-rich host metabasalt to Fe-rich mineralized chlorite schist in the Whalesback, Little Bay, and Colchester areas (after Bachinski, 1973). Field D includes the Little Deer, Rendell-Jackman, Lady Pond, McNeily, Stirling mineralized sequences. Field E is unmineralized chlorite schist and host metabasalt (this study).*

Mottl (1983) also demonstrated that the composition of chlorites and actinolites are diagnostic of the process and position in the hydrothermal convection cell (Figure 7). Chlorites from quartz—chlorite breccias containing sulphide are Fe-enriched relative to chlorite from both chlorite—quartz-poor and chlorite—quartz-rich metabasalts. The Fe-rich chlorite rocks also have an overall metal enrichment and are interpreted to have formed within an upwelling zone (Mottl, 1983). Rocks from the mineralized chlorite-schist zones in the Lushs Bight Group are also characterized by Fe-rich chlorites whereas the host rocks are more Mg-rich (see Figure 4) and probably formed in the downwelling limb with fairly low seawater/rock ratios.

Marten (1971a, b) reported that, in places, pillow lava at the stratigraphic top of the Lushs Bight Group contains labradorite and that secondary chlorite is more abundant than epidote. These rocks then, in general, appear to be fresher or less altered than most of the Lushs Bight Group suggesting that they were not subject to the extensive seafloor hydrothermal alteration characteristic of the rest of the Lushs Bight Group. Mottl (1983) constructed a theoretical model for the structure and evolution of hydrothermal systems at the axis of a mid-ocean ridge (Figure 8). This model demonstrates that "downwelling seawater in axial hydrothermal systems traverses an extremely steep temperature gradient within the upper ophiolite, from less than 50°C in the upper 500 m to greater than 250°C within the upper 1 to 2 km..." (Mottl, 1983). The low temperatures in the upper levels are interpreted to result from an extremely high permeability that allows cold seawater to convect rapidly in and out. Such a model may be envisaged to explain the development

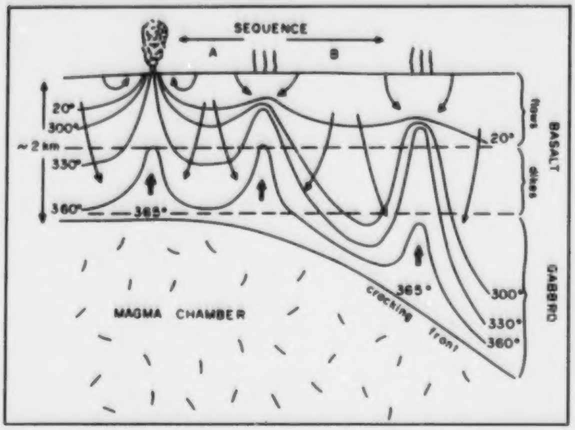


Figure 8. *Model for the structure and evolution of hydrothermal systems at the axis of a mid-ocean ridge (after Mottl, 1983). The diagram is a schematic cross section parallel to the axis. Downwelling indicated by arrows occurs partially in but mainly outside the plane of the diagram. The suggested evolutionary sequence is from shallow to deep circulation (B) as the former magma chamber is penetrated, and from warm to hot vents (A) as the upflow zone is isolated by sulphide deposition. Hot vents may occur near the 300°C isotherm. Rapid shallow circulation keeps the upper crust cold. The sharp drop in temperature near the top of the upflow is due to mixing only; the deeper cooling is adiabatic.*

and distribution of a lower temperature alteration facies within the Lushs Bight Group.

GEOCHEMISTRY

INTRODUCTION

Over two hundred samples of the Lushs Bight Group including lavas, sheeted diabase dykes, and diabase and gabbro intrusives (dykes and sills) were collected for analysis during the course of this study. Representative samples of all rock types were then chosen on the basis of their chemical characteristics as defined by Ti and Zr discriminate diagrams for further detailed and precise analysis. These representative samples were further complemented by detailed sampling undertaken to clarify stratigraphic and structural relationships. A subset of 93 samples was then chosen for additional analyses—43 samples (Tables 3 and 4) were analyzed for a suite of 28 trace elements by inductively-coupled-plasma—mass-spectrometry (ICP-MS) (Jenner *et al.*, 1990), and 50 samples were analyzed for rare-earth elements (REE) by thin film-x-ray fluorescence (TF-XRF). For these later samples, Th was determined by an element specific ICP-MS routine. Based on these analyses, the Lushs Bight Group was divided into a number of geochemical groups or types.

The ICP-MS data and the average compositions of the geochemical groups within the Lushs Bight Group are presented within this chapter (Tables 3, 4 and 5) for quick reference. The averages incorporate both TF-XRF and ICP-MS data. Eleven Sm—Nd isotopic analysis were also done (Table 6).

Twenty-nine samples from the Western Arm, Cutwell and Catchers Pond groups and 14 samples from the Cooper's Cove and Colchester plutons were also analyzed and are presented here for comparison purposes; 32 volcanic and intrusive rocks of unassigned status were also analyzed. Complete datasets for all the rocks analysed are presented in Appendix 2. The reader is referred to Appendix 3 for sampling and analytical methods, statistics and a discussion of what methods were used on which samples.

ALTERATION

Discussion

The geology, metallogeny and geochemistry of the Lushs Bight Group have generally lead to the interpretation of its formation as oceanic crust; however, the exact tectonic environment of its formation has been debatable (Smitheringale, 1973; Strong, 1977; Kean, 1983, 1984; Jenner *et al.*, 1988). The presence of well-developed sheeted dykes clearly indicates an extensional environment similar to that known or postulated to exist at major ocean-basin spreading ridges, back-arc basins and supra-subduction zone environments. Heat flow, mineralogic and isotopic studies of the ocean floor (e.g., Lister 1974) show that seawater circulates through oceanic crust to depths of at least several kilometres and is chemically transformed through reaction with rocks and attain temperatures up to 400 to 500°C. Discharge of hydrothermal fluids circulating in oceanic crust, both at major ocean ridges and back-arc basins, occurs in submarine hot springs (also described as black or white smokers) (e.g., Mottl, 1983). Significant changes in the mineralogy and geochemistry of the oceanic crust accompanies the circulation of seawater (e.g., Humphris and Thompson, 1978a, b). In order to use the geochemistry of ancient volcanic rocks to establish their paleotectonic setting and petrogenetic relationships, it is necessary to establish which element concentrations and/or element ratios have remained unaffected (immobile) or at least still record the original relative abundance patterns.

There are a number of approaches by which the relative mobility of elements can be ascertained, including comparative studies of fresh versus altered portions of individual samples (Bienvenu *et al.*, 1990), comparison of populations of altered versus fresh samples, establishing mobility vectors by comparing altered versus more altered portions of individual flows (e.g., core *vs* rim variations in pillow lavas) (Humphries and Thompson, 1978a, b), consideration of variation diagrams and element-ratio plots to determine if coherent and/or predictable igneous geochemical behaviour is observed (Arndt and Jenner, 1986), experimental studies of basalt—seawater interaction (Seyfried and Mottl, 1982; Hajash, 1984), and analyses of hydrothermal fluids (Michard and Albarede, 1986).

The variables that control the nature of alteration, and therefore element mobility, are: temperature, pressure, relative abundance and nature of primary and secondary phases, textural characteristics of the rock (e.g., degree of crystallinity), permeability, and fluid/rock mass ratio (Mottl and Seyfried, 1980). It is difficult to identify a single variable as being most important; for example, the fluid/rock mass ratio, that according to Mottl and Seyfried (1980) is arguably the most important variable, depends on factors such as "relative rates of fluid flow versus reaction in that locality, which in turn depend on such factors as permeability, surface area, temperature, and type of rock being altered."

The fluid/rock (F/R) mass ratio has a marked effect on chemistry of the hydrothermal solution, the mineralogy of the solids produced and the mobility of elements. Under the conditions that are appropriate for submarine, sub-seafloor alteration, two hydrothermal systems can be defined based on the fluid/rock ratio: rock-dominated hydrothermal system (RDHS) and seawater-dominated hydrothermal system (SWDHS). Mottl and Seyfried (1980) showed that the transition between RDHS and SWDHS occurs in experimental seawater - basalt interaction experiments at a fluid/rock ratio of 50 ± 5 (see Figure 6). The transition between the two systems observed in the experiments is quite abrupt and apparently temperature independent, at least up to about 400°C. The fundamental difference between RDHS and SWDHS results from the role of seawater Mg^+ in generating and maintaining acidity in the hydrothermal solution (Mottl and Seyfried, 1980; Seyfried, 1987). During seawater—basalt interaction, two types of reactions compete to control pH: reactions removing seawater Mg and generating H^+; and silicate hydrolysis reactions generating cations and consuming H^+.

In RDHS ($F/R < 50$) the Mg in seawater is effectively removed and is fixed in the rocks by formation of Mg-rich secondary mineral phases. At low to moderate temperatures (150° to 350°C), Ca replaces Mg, and at very low F/R ratios Na and K replaces Mg; however, at temperatures > 350°C, Ca and Na tend to be fixed in solid phases. The acid-generating stage of alteration in this system is thus relatively early and brief. With the elimination of Mg from the hydrothermal solution, and the resulting neutralization of the solution acidity, the leaching of base and heavy metals ceases. Sodium-metasomatism is dominant in rock-dominated hydrothermal systems that are relatively SiO_2-rich; whereas, Ca-metasomatism dominates systems that are relatively SiO_2-poor (Seyfried, 1987). Typical minerals or mineral assemblages thought to be produced in natural basaltic rocks by a rock-dominated hydrothermal system are smectites, zeolites, prehnite, albite, saponite, actinolitic amphibole, chlorite, epidote, quartz, sphene and pyrite (see Figure 6) (Seyfried, 1987; Mottl and Seyfried, 1980). There are some elements in the basalts that will be effectively partitioned into the fluid phase because there are no sites available (or preferable) to them in the alteration assemblages. These so-called soluble elements include Cl, Br, B, Cs, F, Li, and As; K and Ba may also behave in a similar manner.

In SWDHS ($F/R > 50$) removal of the Mg from seawater is incomplete, because in this fluid-dominated system there are insufficient cations available from the altering basalt to exchange with Mg. Under these conditions, H^+ production is prolonged and the hydrothermal solution is always acidic, which leads to the breakdown of all but the most acid-resistant minerals. The dominant alteration products are chlorite, chlorite—smectite and quartz. Under these conditions base and heavy metals are effectively leached from the rock; Fe is leached from the rock at high temperatures. In SWDHS (because of the acidity and simple alteration mineralogy), several more elements can be added to the list of soluble elements, including K, Ba, Cu, Ca, Na, Mn and Zn (± Fe).

Natural systems are open and isothermal and two important factors apply to them (Mottl and Seyfried, 1980):

1) rock-dominated and seawater-dominated systems can exist at the same time in different localities, and in the same place at different times—depending on locally controlled factors; and,

2) most hydrothermal systems operative during alteration of oceanic crust are rock-dominated. SWDHS are

Table 3. Composition of Lushs Bight Group lavas (ICP-MS). Each geochemical type is listed by decreasing Mg#

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample #	1543328	1543329	1543365	1543334	1543366	1543335	1543337	1543336	1542118	1543347	1542129	1542263	1543326	1542119
Group	BON	BON	BON	BON	BON	BON	BON	BON	BON	BON	LOTI	LOTI	IAT-II	IAT-II
SiO_2	57.5	55.0	56.6	55.7	63.0	59.1	56.8	62.9	54.8	54.7	53.36	51.14	56.4	52.6
TiO_2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.39	0.62	0.9	0.8
Al_2O_3	8.5	8.3	11.4	13.3	12.5	12.8	12.1	10.1	14.6	14.4	15.94	15.85	15.6	17.0
FeO*	8.1	9.5	7.7	9.0	6.2	7.4	8.8	7.7	7.8	8.7	6.93	10.61	7.8	9.4
MnO	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.15	0.17	0.1	0.2
MgO	15.6	17.9	12.3	12.5	8.0	9.4	10.3	8.8	8.1	6.8	5.49	7.67	7.9	9.3
CaO	7.9	7.9	10.1	6.0	5.2	5.5	7.2	6.2	13.2	11.9	17.40	10.41	4.8	6.5
Na_2O	0.5	0.2	1.5	1.7	4.7	5.4	4.0	3.8	1.1	3.1	0.30	2.93	6.2	4.2
K_2O	1.56	1.00	0.12	1.50	0.09	0.10	0.40	0.20	0.13	0.09	0.03	0.31	0.33	0.05
P_2O_5	0.01	0.01	0.02	0.01	0.00	0.01	0.03	0.02	0.01	0.02	0.01	0.04	0.05	0.04
Mg#	77	77	74	71	70	69	68	67	65	58	58	57	64	64
LOI	4.7	4.6	2.9	4.5	1.9	2.6	2.4	1.9	2.4	1.7	2.34	2.66	3.0	3.1
Cr	988	1179	1058	527	485	325	838	953	419	380	157	84	308	179
Ni	205	249	305	80	81	73	176	195	82	81	60	42	122	65
V	208	234	247	260	243	274	264	254	253	253	202	335	259	329
Nb	0.9	0.7	1.1	1.3	1.0	0.9	0.8	0.8	0.9	0.9	0.5	0.4	0.8	0.7
Zr	18	19	24	20	17	22	20	22	17	35	16	33	39	30
Y	4	3	3	4	5	5	2	2	3	3	10	18	18	18
Th	0.44	0.40	0.30	0.54	0.42	0.32	0.25	0.24	0.32	0.57	0.17	0.25	0.20	0.18
La	1.91	1.19	1.31	1.19	1.79	1.30	0.52	0.73	1.14	1.76	0.88	1.80	0.89	1.23
Ce	3.51	2.42	2.69	2.87	3.37	3.07	1.47	1.62	2.50	3.67	1.72	4.02	3.11	3.87
Pr	0.41	0.27	0.33	0.36	0.41	0.41	0.16	0.20	0.29	0.44			0.65	0.65
Nd	1.40	1.12	1.27	1.52	1.68	1.79	0.65	0.88	1.31	1.84	1.72	4.55	4.00	3.91
Sm	0.44	0.32	0.28	0.48	0.52	0.58	0.31	0.24	0.32	0.56	0.91	1.48	1.75	1.53
Eu	0.13	0.08	0.09	0.13	0.14	0.16	0.07	0.08	0.18	0.20	0.54	1.01	0.60	0.62
Gd	0.34	0.28	0.35	0.36	0.49	0.57	0.19	0.20	0.56	0.64	0.97	2.86	2.46	2.25
Tb	0.07	0.06	0.06	0.11	0.11	0.11	0.03	0.04	0.10	0.10		0.00	0.49	0.44
Dy	0.53	0.43	0.49	0.64	0.92	0.87	0.29	0.35	0.83	0.76	1.40	3.70	3.38	3.12
Ho	0.13	0.11	0.10	0.14	0.22	0.20	0.07	0.07	0.20	0.20			0.76	0.72
Er	0.48	0.40	0.40	0.56	0.77	0.60	0.23	0.27	0.67	0.65	1.40	1.38	2.20	2.03
Tm	0.08	0.07	0.06	0.09	0.11	0.10	0.04	0.05	0.09	0.11			0.31	0.30
Yb	0.39	0.34	0.59	0.90	0.89	0.80	0.39	0.41	0.84	0.67	1.18		2.12	2.05
Lu	0.12	0.08	0.10	0.14	0.17	0.14	0.06	0.07	0.12	0.15			0.32	0.29

Major elements in wt. %, trace elements in ppm. FeO* is total iron. Recalculated volatile-free to 100%.

crucial for the development of massive sulphide deposits, but these extreme conditions are not the norm.

The mobility of elements not only depends on the nature and characteristics of the hydrothermal system, but also on the chemistry of the various elements themselves. For example, there are natural groupings of elements that seem to behave in a coherent manner or are not affected by alteration processes. Traditionally, in describing rock chemistry the primary division of elements is based on percentage present, i.e., major (>1 wt.%), minor (0.1—1 percent wt.%) and trace elements (<0.1 percent wt.%). Obviously, element groupings defined in this manner can change, for example, in mafic volcanic rocks of supra-subduction zone settings TiO_2 can range from ~0.1 to > 1.5 percent and K_2O can range from <0.1 to >2 percent. The field strength of elements, i.e., ionic radius/ionic charge, is often used when studying alteration, petrogenesis and tectonic associations of mafic volcanic rocks (Saunders *et al.*, 1980). It, nonetheless, is somewhat inconsistent because Na is not usually defined as a low-field-strength-element (LFSE) even though it is like the LFSEs K, Rb and Cs. Also calcium, an alkaline earth metal like Sr and Ba, is by definition a LFSE, but is never discussed in such a manner. Unfortunately, there is no easy or rigourous way out of this dilemma, except to clearly define those element groups that are to be used during the discussion of element mobility during alteration. These are as follows:

MAJOR ELEMENTS—SiO_2, Al_2O_3, FeO*[2], MgO;
LFSE (low-field-strength-elements)—Ca, Na, K, Mn, Cs, Rb, Ba, Sr, Th, U, Pb;

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[2] * Total Fe as FeO

Table 3. Continued

15 1542237 IAT-II	16 1542046 IAT-II	17 1542249 IAT-II	18 1542024 IAT-II	19 1543354 IAT-II	20 1542036 IAT-II	21 1543325 IAT-I	22 1542116 IAT-I	23 1543348 IAT-I	24 1542004 IAT-I	25 1542266 IAT-I	26 1542151 IAT-I	27 1543349 IAT-I	28 1542267 IAT-I	29 1543344 MORB	30 1543362 DACITE
55.4	50.9	51.9	49.9	55.0	52.8	54.1	54.5	51.6	51.8	53.5	56.0	61.4	62.9	50.9	73.8
0.9	0.9	0.9	0.9	1.0	1.2	0.7	0.7	0.8	0.9	1.0	0.9	1.0	1.2	1.5	0.3
15.2	15.9	15.4	15.4	15.2	16.0	13.4	15.7	17.2	15.7	16.3	15.8	13.0	13.4	15.4	13.1
9.1	9.9	10.6	9.9	10.4	12.1	8.3	7.9	10.0	10.3	11.0	10.8	9.3	8.9	10.2	4.6
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.1
8.1	8.2	8.5	7.5	6.8	6.4	7.1	6.5	7.7	7.0	6.2	4.7	3.7	3.0	6.6	1.0
7.7	9.9	9.5	12.2	6.6	6.1	12.4	10.7	8.6	10.3	9.3	6.5	7.3	3.6	11.3	0.7
3.3	3.9	2.9	3.9	4.7	4.9	3.7	3.7	3.9	3.7	2.4	4.9	3.9	6.6	3.6	6.1
0.13	0.19	0.15	0.08	0.02	0.36	0.07	0.17	0.06	0.08	0.07	0.09	0.15	0.21	0.15	0.35
0.06	0.04	0.05	0.06	0.10	0.07	0.05	0.04	0.05	0.05	0.07	0.10	0.07	0.09	0.14	0.04
61	60	59	58	54	49	60	59	58	55	50	43	42	38	54	29
2.7	3.4	3.4	3.7	7.4	2.4	1.9	1.8	3.9	2.6	4.2	2.8	1.7	1.1	3.4	1.2
81	166	92	199	23	35	209	94	174	67	61	0	0	22	96	0
37	49	41	57	12	22	76	38	57	30	29	12	0	0	30	0
344	336	347	309	406	464	248	266	284	314	300	439	379	368	311	0
1.0	0.5	0.8	0.8	0.9	0.6	0.5	0.5	0.6	0.8	0.8	1.4	0.9	1.3	3	4.6
32	36	29	37	52	32	32	16	33	37	37	28	54	46	114	162
21	20	21	20	26	26	17	17	23	21	22	21	25	25	36	67
0.28	0.12	0.17	0.12	0.20	0.13	0.13	0.11	0.09	0.22	0.15	0.30	0.20	0.23	0.35	0.74
1.91	1.07	1.34	1.29	1.96	1.29	0.67	0.62	0.94	1.38	1.31	2.60	1.82	2.13	4.22	9.74
5.60	3.80	4.31	4.46	5.81	5.09	2.22	2.26	3.36	4.48	4.68	7.12	6.09	6.75	12.52	24.13
0.88	0.68	0.77	0.79	1.01	0.93	0.44	0.41	0.67	0.74	0.82	1.00	1.10	1.13	2.08	4.22
4.75	4.23	4.80	4.63	5.79	5.70	2.60	2.65	3.97	4.29	5.00	5.28	6.02	6.34	10.82	21.50
1.84	1.66	1.81	1.84	2.18	2.31	1.22	1.25	1.72	1.72	1.96	1.78	2.30	2.24	3.72	7.15
0.76	0.71	0.74	0.87	0.87	0.89	0.48	0.39	0.52	0.73	1.00	0.70	0.69	0.79	1.44	1.55
2.57	2.49	2.41	2.68	3.17	3.43	1.90	1.90	2.52	2.51	2.81	2.54	3.01	3.31	4.78	8.83
0.52	0.51	0.48	0.51	0.63	0.66	0.40	0.42	0.51	0.49	0.57	0.51	0.60	0.64	0.95	1.75
3.82	3.57	3.37	3.65	4.52	4.58	2.85	2.95	3.88	3.52	3.99	3.60	4.18	4.45	6.18	11.95
0.87	0.83	0.78	0.84	1.00	1.05	0.67	0.69	0.88	0.83	0.91	0.87	0.97	1.01	1.38	2.56
2.46	2.33	2.41	2.24	2.91	2.85	1.88	1.94	2.50	2.30	2.58	2.41	2.79	2.84	3.87	7.96
0.35	0.33	0.34	0.32	0.41	0.39	0.28	0.27	0.35	0.33	0.37	0.34	0.40	0.40	0.56	1.19
2.43	2.10	2.34	2.13	2.84	2.65	1.83	1.83	2.30	2.25	2.47	2.32	2.69	2 69	3.53	8.37
0.36	0.30	0.34	0.29	0.45	0.36	0.2[illegible]	0.27	0.35	0.33	0.35	0.33	0.40	0.37	0.56	1.34

HFSE (high-field-strength-elements)—Ti, P, Y, Zr, Hf, Nb, Ta;

REE (rare-earth-elements)—La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, Lu.

- LREE or the light REE—La, Ce, Pr, Nd
- MREE or the middle REE—Sm, Eu, Gd, Tb
- HREE or the heavy REE—Dy, Ho, Er, Yb, Lu

TE (transition elements)—Cr, Ni, Sc, V

A few points of clarification about these groupings are outlined below:

1) Manganese oxide is usually present at levels of 0.1 to 0.3 percent, i.e., it is on a weight percentage basis a minor element. However, with allocation of Ti and P to the HFSE, a separate minor element grouping seems pointless.

2) Yttrium is left in the HFSE, rather than with the REE (it is not a lathanide). Ti and P are here considered as HFSE as suggested by Saunders *et al.* (1980).

3) Sodium and Ca are alkali metals and are included in the LFSE.

Methodology

During this study, geochemical sampling was directed primarily toward solving petrogenetic, tectonic, and structural rather than alteration-related problems. Samples displaying anomalous alteration, such as pillow rims, highly fractured rocks, dyke margins, and immediate zones of alteration around massive sulphide deposits, were not collected, except where this complemented the primary aims. Thus, the evaluation of alteration is limited to studying igneous geochemical behaviour on variation diagrams and element ratio plots, to comparisons with presumably equivalent modern rocks, and by constraints derived from experimental and other alteration studies compiled from the literature.

In order to use variation diagrams and element ratio plots to establish igneous trends, it is necessary to plot one element versus an element or element ratio that illustrates the degree of fractionation. In fresh rocks, this is done by using SiO_2 to establish Harker variation plots, by complex ratios (Kuno's Solidification Index or the Differentiation Index), or by ratios based on Fe and Mg, e.g., FeO*/Mgo

Table 4. Composition of Lushs Bight Group dykes (ICP-MS). Each geochemical type is listed in order of decreasing Mg#

Column	1	2	3	4	5	6	7	8	9	10	11	12	13
Sample #	1542206	1543332	1543345	1543361	1543327	1542097	1543346	1543352	1543351	1543331	1543338	1543333	1543359
Group	BON	BON	BON	BON	LOTI	IAT-II	IAT-II	IAT-1	IAT-1	CAB	CAB	CAB	FELSITE(?)
SiO_2	57.0	58.6	60.1	60.7	54.9	52.4	57.0	57.6	62.1	52.7	52.2	53.7	70.5
TiO_2	0.2	0.3	0.2	0.2	0.7	1.0	1.3	0.9	0.8	0.4	0.6	0.6	0.2
Al_2O_3	9.3	15.4	15.4	15.9	15.7	15.1	14.0	15.2	11.8	13.7	12.5	19.0	11.9
FeO*	8.0	8.4	7.7	8.3	8.7	10.7	11.7	12.2	8.6	10.1	10.1	9.0	5.6
MnO	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1
MgO	11.3	7.3	6.2	3.2	6.5	7.8	4.9	4.5	2.5	10.6	10.3	6.8	0.1
CaO	12.0	6.6	5.3	7.6	8.1	9.0	6.5	4.3	13.4	8.5	10.2	5.1	11.3
Na_2O	2.0	2.9	4.8	3.9	5.0	3.7	4.2	4.4	0.5	3.4	2.5	4.6	0.3
K_2O	0.10	0.41	0.07	0.10	0.29	0.03	0.13	0.54	0.11	0.47	1.19	0.70	0.01
P_2O_5	0.03	0.02	0.03	0.02	0.05	0.06	0.10	0.08	0.07	0.06	0.16	0.30	0.03
Mg#	72	61	59	41	57	56	43	39	34	65	65	57	
LOI	3.9	3.5	2.7	2.2	2.5	2.8	2.2	3.0	1.4	3.6	3.5	4.2	1.2
Cr	1349	46	176	31	226	154			48	496	533		
Ni	337	29	65	11	60	42				106	90		
V	229	278	232	286	292	336	435	448	304	348	351	227	
Nb	1.2	0.6	1.1	1.0	0.8	0.8	1.6	1.4	1.0	1.3	1.4	1.4	2.6
Zr	17	33	43	47	39	44	58	50	57	44	51	62	146
Ti	998	1642	1388	1236	4026	6002	7784	5548	5033	2665	3685	3829	1487
Y	3	5	9	7	18	26	30	19	22	11	14	19	43
Th	0.27	0.41	0.97	0.50	0.22	0.15	0.24	0.53	0.16	1.03	2.20	2.52	0.51
La	1.58	1.75	3.06	2.09	1.41	1.41	2.45	2.53	1.82	5.07	7.57	12.7	4.32
Ce	3.02	3.75	6.25	4.51	3.85	4.83	7.44	6.36	5.31	10.2	15.5	26.0	12.2
Pr	0.32	0.49	0.76	0.57	0.64	0.86	1.29	1.01	0.89	1.33	2.09	3.51	2.07
Nd	1.30	2.01	3.44	2.46	3.66	5.19	6.97	5.22	4.74	5.94	9.08	14.0	10.6
Sm	0.30	0.62	0.93	0.73	1.49	2.04	2.71	1.94	1.78	1.56	2.49	3.34	3.96
Eu	0.16	0.23	0.26	0.32	0.63	0.86	1.01	0.73	0.93	0.54	0.74	1.03	1.40
Gd	0.37	0.71	0.98	0.82	2.15	3.03	3.66	2.27	2.47	1.59	2.32	3.18	5.26
Tb	0.06	0.14	0.18	0.18	0.44	0.61	0.74	0.47	0.49	0.31	0.39	0.55	1.11
Dy	0.48	0.94	1.44	1.23	3.18	4.38	5.12	3.32	3.56	2.05	2.62	3.67	7.90
Ho	0.11	0.22	0.34	0.27	0.72	1.00	1.15	0.75	0.78	0.46	0.56	0.83	1.76
Er	0.34	0.71	1.09	0.85	2.01	2.81	3.38	2.24	2.19	1.42	1.53	2.35	5.44
Tm	0.05	0.11	0.19	0.13	0.29	0.39	0.51	0.36	0.31	0.19	0.23	0.32	0.81
Yb	0.41	0.78	1.35	1.02	1.91	2.74	3.36	2.25	2.15	1.32	1.44	2.37	5.43
Lu	0.07	0.13	0.22	0.18	0.29	0.37	0.50	0.35	0.32	0.22	0.22	0.38	0.80

Major elements in wt.%, trace elements in ppm. FeO* is total iron. Recalculated volatile-free to 100%.

and Mg# (Mg# = atomic Mg/(Mg+Fe). In all of these situations the mobility of the major elements (± LFSE) is a potential, if not major, concern. Furthermore, source heterogeneity can complicate the use of elements, such as Ti, making it difficult to discriminate between coherent behaviour due to alteration and primary petrogenetic effects. For example, formation of secondary muscovite may lead to a fairly coherent K and Rb behaviour that does not reflect their original igneous variation (Figure 9a); whereas the considerable scatter in TiO_2 *vs* K_2O (Figure 9b) could be caused by either heterogeneity or alteration. However, the relative coherent behaviour between TiO_2 and Zr (Figure 9c) is almost certainly due to primary igneous processes.

A discussion of alteration effects within each of the significant element groupings follows.

Major Elements

Significant mobility in major elements has been documented by a number of workers, (e.g., Pearce, 1975; Coish, 1977); Humphris and Thompson, 1978a). Examination of the types of reactions involved in seawater—basalt interaction (for example, the formation of chlorite and smectite), clearly indicates mobility. In RDHS, Fe and Al are relatively stable and not extensively replaced by Mg (Seyfried, 1987); Si can be either enriched or depleted (Pearce, 1975; Garcia, 1978). Studies on rim *vs* core chemical variations in altered pillow lavas (Humphris and Thompson, 1978a) should absolute changes in the ratios of FeO*/MgO and in the Mg# from 0.85 to 1 and 61 to 67, respectively. These changes, on the order of 10 percent, are similar to changes noted in experimental basalt glass—seawater alteration studies (Seyfried *et al.*, 1978) for RDHS. Such variations are thus not necessarily indicative of changes in Fe/Mg in crystalline rocks and demonstrate the reason for avoiding the glassy pillow rims. Alt and Emmermann (1985) have demonstrated that under rock-dominated conditions increasing greenschist facies metamorphism (alteration) of fresh basalt with depth shows no systematic variation in Mg# and that the variation is on the order of 5 percent. Changes in Fe/Mg ratios of 5 to 10 percent during moderate temperature (<400°C), rock-dominated alteration thus presents detailed and reliable fractionation modelling. Alteration is even more intense and pervasive in seawater-dominated alteration, because of the high and prolong acidity.

Low-Field-Strength-Elements (LFSE)

Mobility of these elements is to be expected during alteration in either RDHS or SWDHS, because many of the LFSE are so-called "soluble" elements. However, predicting directions and the magnitude of change can be extremely difficult and dependent on mineralogy (cf. Berger *et al.*, 1988). The formation of spilites (e.g., Cann, 1969; Hughes, 1972) has been a topic of considerable discussion and Hughes (1972) devised a plot to show the variation in Na and K as a result of spilitization. It is generally accepted that Ca, Na and K should not be used to classify altered igneous rocks (Pearce, 1975; Garcia, 1978). Manganese can also be mobilized during alteration, particularly at high temperatures and in SWDHS; however, Mullen (1983) has shown that the behaviour of Mn in some altered rocks, especially relative to the high-field-strength-elements Ti and P, is consistent with that in the primary igneous precursor (see also Bienvenu *et al.*, 1990). Nonetheless, Mullen (1983) noted that in rocks where Ca has been mobile as a result of significant carbonitization Mn behaviour may be suspect. Cesium, Rb, Pb and U are easily mobilized in altered rocks (Palmer and Edmond, 1989; Michard *et al.*, 1983; Bienvenu *et al.*, 1990), and are not useful for identifying primary igneous signatures. The behaviour of Sr and Ba is less well understood and whereas they are certainly mobile, they appear to be less so than Cs, Rb, U, Na and K (Bienvenu *et al.*, 1990). The behaviour of Sr and Ba may be linked to the presence of plagioclase, and how it has been altered. (For example, in the Snooks Arm Group basalts, the behaviour of Sr and Ba was shown to be predictable based on the petrology of the basalts (Jenner and Fryer, 1980)). However, it is generally assumed that they are mobile and not necessarily indicative of the original magma chemistry. Although considered a LFSE, the behaviour of Th appears to be more like that of a HFSE and is generally taken to be immobile during alteration (Wood *et al.*, 1979; Bienvenu *et al.*, 1990). Bienvenu *et al.* (*op. cit.*) noted some mobility of Th during alteration of basaltic glass but suggested it could behave differently in crystalline samples.

High-Field-Strength-Elements (HFSE)

The widespread use of HFSE in constructing tectonic discrimination diagrams (Pearce and Cann, 1971, 1973; Winchester and Floyd, 1977; Meschede, 1986) reflects the early recognition that Ti, Y, Zr and Nb are immobile during seawater alteration and metamorphism (Cann, 1970). Geochemical studies of fresh oceanic basalts have shown that the behaviour of Ta and Hf is similar to that of Nb and Zr (e.g., Briqueu *et al.*, 1984), respectively, and their immobility during alteration is predictable (Saunders *et al.*, 1980; Wood *et al.*, 1979; Bienvenu *et al.*, 1990). Winchester and Floyd (1977) suggested limited mobility for P but the mobility was insufficient to significantly alter its discriminant capabilities. Mullen (1983) has also concluded that P can be mobile in cases of severe carbonitization. Finlow-Bates and Stumpfl (1981) concluded that in the intensely altered zones surrounding volcanogenic massive sulphides Nb and Y could be mobile whereas Ti and Zr remained immobile. Their study deliberately made use of extremely altered samples, which were either tuffs or tuffaceous sediments. A study on altered basalts (Williams and Floyd, 1981), using fission track and microprobe studies to trace U and HFSE mobility, found that carbonate complexes can cause element mobility, but it was not clear if elements had actually been lost from the rocks.

Rare-Earth Elements (REE)

Mobility of the REE is one of the most contentious issues in alteration studies of basaltic rocks and there appear to be no simple rules to explain their behaviour (Humphris, 1984). Bienvenu *et al.* (1990) and Hellman *et al.* (1979) have suggested that the REE can be mobilized even during low-temperature alteration of basaltic glasses and lavas. Alternatively, others (e.g., Herrmann *et al.*, 1974); Garcia, 1978); Pearce, 1980; and Saunders *et al.*, 1980) have argued that the REE are immobile during low- to moderate-temperature alteration of basalts. The difficulty in understanding REE behaviour reflects our generally poor knowledge of REE complexes at high temperatures and the differences in behaviour of the REE with different dominant fluid species, i.e., chlorine, fluoride and carbonate complexes. Experimental studies by Menzies *et al.* (1979), Hajash (1984), Sverjensky (1984) and studies of hydrothermal fluids vented on modern oceanic ridges and other environments (Michard and Albarede, 1986) offer some insights.

Table 5. Average compositions for major geochemical groups within the Lushs Bight Group lavas and dykes

Column	1	2	3	4	5	6	7	8
Group	BON	BON	LOTI	LOTI	LOTI-F	LOTI-FH	IAT-II	IAT-II
Type	Lava	Dyke	Lava	Dyke	Dyke	Dyke	Lava	Lava
Mg #	70	66	55	59	44	38	63	48
SiO_2	57.6	57.5	55.0	53.8	54.3	57.3	53.3	53.4
TiO_2	0.1	0.2	0.6	0.4	0.6	0.7	0.8	0.7
Al_2O_3	11.8	13.3	16.2	16.8	17.0	17.1	15.9	14.9
FeO*	8.1	8.1	7.2	8.0	10.1	9.4	9.3	8.0
MnO	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2
MgO	11.0	8.9	4.9	7.4	4.9	3.3	8.8	7.5
CaO	8.1	8.8	13.4	10.3	9.3	7.8	7.6	11.4
Na_2O	2.6	2.9	2.5	2.9	2.3	2.7	4.0	3.9
K_2O	0.5	0.1	0.1	0.2	1.2	1.3	0.1	0.1
P_2O_5	0.02	0.02	0.04	0.03	0.10	0.12	0.05	0.04
Cr	715	441	122	85	31		168	235
Ni	153	122	49	45	21		65	79
V	249	263	272	269	314	285	293	256
Nb	1.0	1.3	1.0	0.9	2.3	4.1	0.9	0.5
Zr	21	23	23	18	41	68	33	29
Y	4	6	15	9	19	25	21	16
Th	0.38	0.58	0.25	0.40			0.20	0.15
La	1.28	2.1	1.3	1.4			1.34	1.6
Ce	2.72	4.1	2.6	2.2			4.19	5.7
Pr	0.33	0.53					0.72	0.93
Nd	1.35	2.2	2.7	1.8			4.22	6.7
Sm	0.41	0.6	1.0				1.71	2.7
Eu	0.13	0.2					0.66	1.1
Gd	0.40	0.7	1.6	1.2			2.43	3.9
Tb	0.08	0.13					0.48	0.66
Dy	0.61	0.9	2.4	1.7			3.44	4.7
Ho	0.14	0.22					0.78	1.05
Er	0.50	0.7	1.6	1.3			2.23	3.44
Tm	0.08	0.12					0.32	0.39
Yb	0.66	0.84	1.4	1.1			2.20	3.38
Lu	0.12	0.14					0.32	0.36

Major elements in wt.%, trace elements in ppm. FeO* is total iron. Recalculated volatile-free to 100%.

Both field- and labratory-based studies indicate that Eu can be mobile during alteration processes. This reflects the ability of Eu to exist in divalent or trivalent oxidation states (see Sverjensky, 1984). Interpretation of the origin and/or the magnitude of Eu anomalies in altered volcanic rocks can be contentious (Whitford and Cameron, 1987). If there are strong petrogenetic arguments to support the formation of either a positive or negative Eu anomaly (e.g., Jenner and Fryer, 1980), then a primary igneous origin can be suggested. However, in altered chlorite-rich samples, substantial Eu anomalies may be generated by secondary processes (Whitford *et al.*, 1988).

The potential for internal fractionation within the REE (i.e., LREE versus HREE) and of the REE from the HFSE is also a concern because this may lead to incorrect interpretations of igneous processes and/or to totally obliteration of key petrogenetic and tectonic indicators. While some evidence for elective LREE enrichment exists (Frey *et al.*, 1974; Wood *et al.*, 1976; Hellman *et al.*,

Table 5. Continued

9 IAT-II Dyke 54	10 IAT-I Lava 63	11 IAT-I Lava 46	12 IAT-I Dyke 51	13 IAT Lava 57	14 IAT Lava 56	15 IAT Lava 56	16 MORB Dyke 53	17 CAB Dyke 62
52.0	53.4	56.9	54.4	51.7	51.9	52.4	49.9	52.9
1.0	0.7	1.0	0.9	0.8	0.9	0.9	1.6	0.6
15.6	14.9	14.8	15.7	15.6	15.7	15.8	15.4	15.0
10.8	8.0	10.0	10.0	9.4	10.0	10.0	11.1	9.7
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
7.1	7.5	4.8	6.2	7.1	7.2	7.3	7.1	9.2
9.9	11.4	7.8	8.9	11.8	10.4	9.6	11.3	7.9
3.0	3.9	4.3	3.3	3.3	3.4	3.6	2.7	3.5
0.3	0.1	0.1	0.2	0.1	0.2	0.1	0.5	0.8
0.07	0.04	0.08	0.08	0.07	0.06	0.06	0.15	0.17
108	235	30	122	99	101	109	148	515
37	79	18	33	38	41	39	46	98
354	256	387	325	302	309	320	328	309
1.9	0.5	0.9	1.1	1.5	1.2	0.7	5.5	1.3
45	29	40	43	34	38	35	105	52
27	16	22	24	21	23	21	38	15
0.24	0.15	0.23	0.35	0.12	0.19	0.15		1.9
1.9	1.0	2.2	1.8	1.5	1.6	1.24		8.46
5.3	2.9	6.2	5.0	4.0	4.2	4.15		17.27
1.07	0.44	1.05				0.74		2.31
5.5	3.3	5.4	4.8	4.6	4.9	4.42		9.66
2.2	1.3	2.0	1.8	1.9	1.9	1.77		2.46
1.0	0.48	0.8		0.7	1.1	0.73		0.77
3.5	1.94	2.8	2.6	2.4	3.1	2.56		2.36
0.67	0.40	0.56				0.51		0.42
4.2	2.7	3.7	3.4	3.5	3.6	3.68		2.78
1.08	0.67	0.92				0.84		0.62
2.5	1.88	2.7	2.1	2.0	2.4	2.40		1.77
0.5	0.28	0.37				0.34		0.25
2.6	1.81	2.50	2.5	1.9		2.28		1.71
0.43	0.29	0.37				0.34		0.28

1979; Fryer and Jenner, 1978), studies of hydrothermal fluids, experimental studies and natural rock studies (e.g., Michard and Albarede, 1986; Hajash, 1984; Herrmann *et al.*, 1974; Whitford *et al.*, 1988; Swinden *et al.*, 1990) indicate there is generally little evidence to support significant overall REE mobility or fractionation in RDHS. However, alteration of originally glassy pillow lava rims or the presence of significant amounts of carbonate in the alteration fluids can cause selective REE mobility, especially LREE. Dunning *et al.* (1991) presented evidence for HREE mobility during alteration of mafic volcanic rocks in an Ordovician sequence in central Newfoundland, but the patterns resulting from alteration are clearly different from those of the precursor igneous rocks. However, it is much more difficult to distinguish LREE enrichment during alteration, since the patterns produced can mimic igneous rock patterns. The mere presence of carbonate does not necessarily imply substantial LREE enrichment, for example carbonitized komatiites (Arndt and Jenner, 1986) at Kambalda have LREE depleted

Table 6. Sm—Nd isotopic data for Lushs Bight Group volcanic rocks

SAMPLE NUMBER	GEOCHEMICAL GROUP	$^{143}Nd/^{144}Nd_m$	2 sem	$^{147}Sm/^{144}Nd$	$\epsilon Nd_{(T)}$
1542118	BON	0.512704	20	0.1722	+2.8
1542206	BON	0.512433	10	0.1381	-0.3
1543361	BON	0.512520	17	0.1520	+0.5
1542024	IAT-II	0.513165	20	0.2372	+7.7
1542036	IAT-II	0.513112	13	0.2447	+6.2
1542249	IAT-II	0.513147	18	0.2377	+7.3
1542004	IAT-I	0.513047	32	0.2357	+5.5
1542116	IAT-I	0.513018	05	0.2737	+2.5
1542151	IAT-I	0.513003	20	0.2064	+6.5
1542266	IAT-I	0.513090	11	0.2428	+5.9
1542267	IAT-I	0.513095	10	0.2253	+7.1

Age of 495 Ma used in calculating epsilon values; m = measured, sem = standard error mean
CHUR (today) - $^{143}Nd/^{144}Nd = 0.51264$ & $^{147}Sm/^{144}Nd = 0.1967$
$^{143}Nd/^{144}Nd$ corrected for fractionation to $^{146}Nd/^{144}Nd = 0.7219$
All samples, excluding the boninite dykes 1542206 and 1543361, are from pillow lavas

patterns consistent with their isotopic composition. In summary, there is no *a priori* assumption required that LREE enrichment occurs in all altered volcanic rocks, or even those having significant carbonate content. Conversely care must be taken in sampling and in data evaluation to minimize potential problems and prove internal consistency with other element groups.

Transition Elements (TE)

Scandium, V, Ni and Cr are generally immobile during alteration of komatiites (Arndt and Jenner, 1986), modern ocean-floor basalts (Humphris and Thompson, 1978b; Shervais, 1982), ophiolitic basalts (Pearce, 1975; Coish, 1977; Shervais, 1982) and other basalt types (Winchester and Floyd, 1977). The conditions under which V, Cr and Ni stay immobile extends up to that included in SWDHS (see Seyfried and Mottl, 1982).

GEOCHEMICAL GROUPS

There are three major, and a number of minor, fairly consistent geochemical groups present in both the Lushs Bight Group lavas and dykes and they are illustrated on plots of TiO_2 versus Mg# (Figure 10). However, the stratigraphic and tectonic significance of these groups and their spatial distribution and relationships is still not fully understood. Note that, for example, the sheeted diabase dykes drom different geographic areas have different geochemical constituents. Data from Tables 3 and 4 and the TF-XRF data in Appendix 2 are used in these plots. Table 5 gives the average composition for the major geochemical types.

The most geochemically distinct group of dykes and lavas are the low Ti and high Mg# rocks that are classified as boninites (Figure 10). Primary identification of this group of rocks as boninites was made using an extended REE plot, modified to exclude mobile LFSE (Figure 11). These rocks are also characterized by high SiO_2 (~57 percent) and low Al_2O_3 (see Tables 3, 4 and 5). On the Jensen classification plot (Jensen, 1976) (Figure 12) the boninites plot in the high-Mg tholeiite and basaltic komatiite tectonic environment fields. Their high SiO_2 content, however, does not allow them to be classified on Mullen plots (Mullen, 1983). The boninitic dykes have on average a higher TiO_2 content than the lavas (see Table 5 and Figure 10).

The majority of dykes and lavas in the Lushs Bight Group contain between 0.6 to 1.3 percent TiO_2 and have Mg# between 45 and 65 (Figure 10) and have a broadly dominant tholeiitic nature (Figures 13 and 14). These rocks also show evidence of both Fe and Ti enrichment with increasing degree of fractionation. The majority of the tholeiites are of island-arc origin (Ewart, 1976; Gill, 1981) (Figure 15). This major geochemical group within the Lushs Bight Group is herein referred to as island-arc tholeiite (IAT). The scatter in FeO* and the presence of some calc-alkalic basalts may be due to either alteration or primary processes; although the dataset was previously screened to identify calc-alkaline rocks. A redistribution of

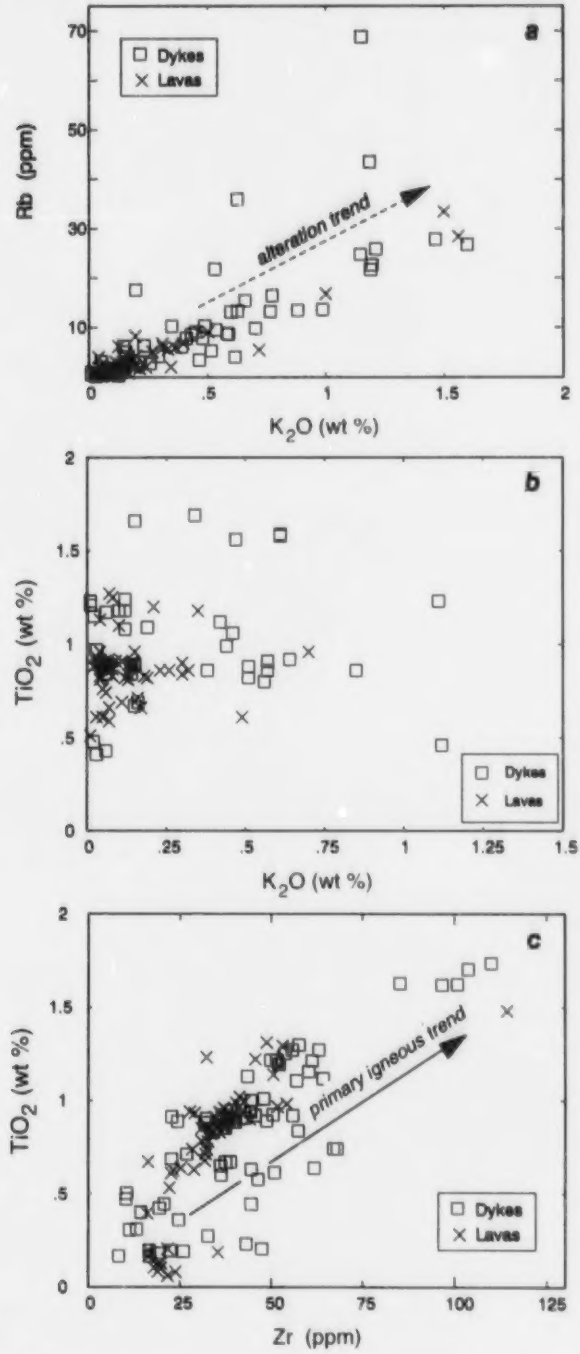


Figure 9. *Comparisons of alteration effects on K_2O, Rb, Zr and TiO_2.*

FeO*, MgO and Al_2O_3 undoubtedly has occurred in these rocks and many of the andesite and basalts actually plot in the continental basalt tectonic field on some ternary diagrams.

Subdivision of the IAT groups into Type I and II is done primarily to highlight the heterogeneity in TiO_2 for a given Mg# (Figure 10) and is not based on any petrogenetic or other geochemical parameters. Figure 13 shows that Type I lavas are slightly displaced toward the Al_2O_3 corner in the AFM plot and they have lower FeO* for a given FeO*/MgO ratio (Figure 14). Differences between Type I and II dykes, although reflected in the TiO_2 content, are generally less evident in the FeO*, MgO and Al_2O_3 content (Figures 13 and 14).

A third geochemical type is characterized by TiO_2 contents intermediate between the IAT and boninites (Figure 10) and is referred to as low titatium tholeiites (LOTI) (cf. Brown and Jenner, 1989). A characteristic feature of the LOTI lavas is their low FeO* relative to FeO*/MgO (see Figure 14). The LOTI lavas plot in either the calc-alkalic or are transitional between the island-arc tholeiitic and calc-alkalic tectonic fields (Figures 13 and 15).

Two dyke samples plot clearly within the LOTI field as defined for the lava field (Figure 10) and an average composition for these is given in Table 5. A third dyke sample plots between the IAT and LOTI fields, but because of its high SiO_2 and low Ti and FeO* relative to rocks with similar Mg#, it is included with the LOTI. An additional ten dyke samples plot outside the LOTI fields and below the IAT field as defined for the lavas. They have been classified as LOTI-FH and LOTI-F (F=fractionated, H=relatively higher Ti) (Figure 10). Samples within these two subdivisions of the LOTI group fall mainly within the tholeiitic field (Figures 13 and 14) with a transgression into the calc-alkalic field (Figure 15).

There are a number of minor and less extensively developed geochemical types within the Lushs Bight Group. A group of lavas and dykes with high TiO_2 and P_2O_5 relative to the boninites, LOTI and IAT, have non-arc signatures and are similar to MORB tholeiites (Figures 10 and 15). Other dykes with high TiO_2, generally > 1.8 percent, have been screened out from the Lushs Bight Group because it could be demonstrated that they were unrelated. Other dykes have a calc-alkalic affinity (CAB) (Figures 10 and 15); all of these dykes intrude the boninitic lavas. Note that the CAB dykes have a Mg # of 57-65. Three dykes do not plot in any of these fields and are included for completion purposes only.

Felsic (dacite—rhyolite) dykes and lavas (Tables 3 and 4) are a minor component of the Lushs Bight Group. The lavas are high in Na_2O and low in K_2O, and have

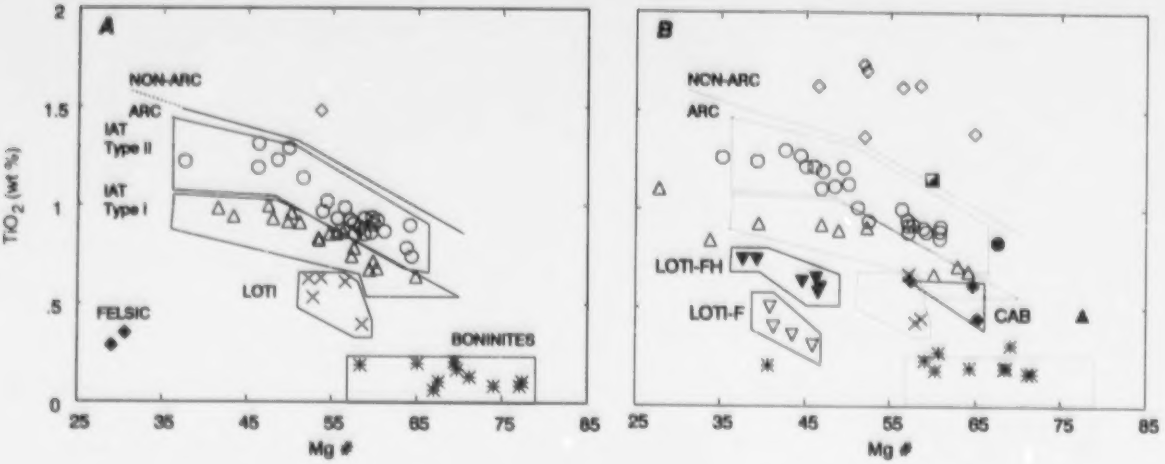


Figure 10. *TiO_2 vs Mg# diagram showing the major geochemical groups in the Lushs Bight Group (A—lavas, B—dykes). Non-arc/arc division line based on complete trace element evaluations for the Lushs Bight Group and is not intended for use with other rocks. Dotted field boundaries in B indicate groups defined for the lavas; additional groups present only for the dykes are shown by solid lines (e.g., LOTI-FH, LOTI-F, CAB). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure.*

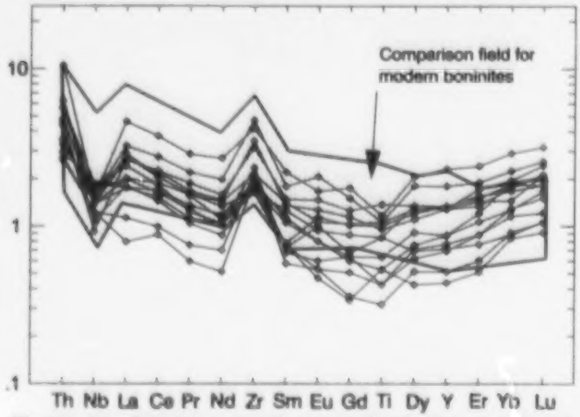


Figure 11. *Primitive mantle normalized plot of selected (immobile) elements for modern boninites and Lushs Bight Group boninites. Data for modern boninites from Jenner (1981, 1982). Normalizing values after Hofmann (1988).*

similarities to other felsic volcanic rocks in the Notre Dame Bay area (Jenner and Szybinski, 1987; Swinden *et al.*, 1990). The dyke is most likely either a felsite or an epidosite. It is epidotized and has high SiO_2 and CaO and low Na_2O and K_2O contents. It is not plotted on Figure 10 because of its low Mg# and in general, it is not plotted on diagrams using major element ratios. This dyke, from the Little Bay Road area, north of Springdale intrudes Lushs Bight Group dykes, including possibly boninitic dykes.

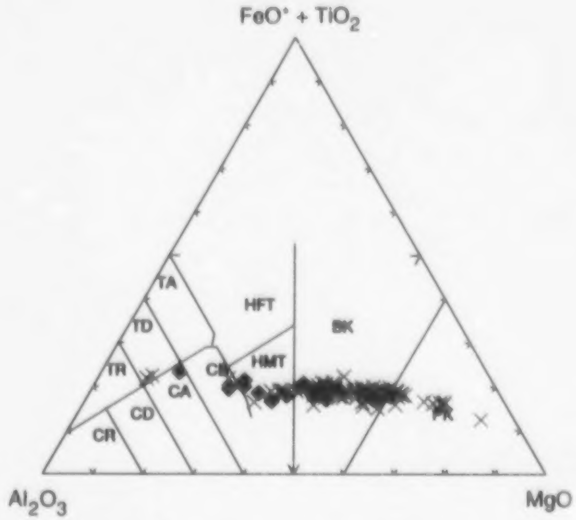


Figure 12. *AFM ternary (cation percent; Jensen, 1976) plot for boninites of the Lushs Bight Group (solid diamonds) and modern boninites (crosses). Data for modern boninites from Jenner (1981, 1982). HFT = high Fe tholeiite; HMT = high Mg tholeiite; BK = basaltic komatiite; PK = peridotitic komatiite; T = tholeiite; C = calc-alkaline. (A = andesite, B = basalt, D = dacite, R = rhyolite).*

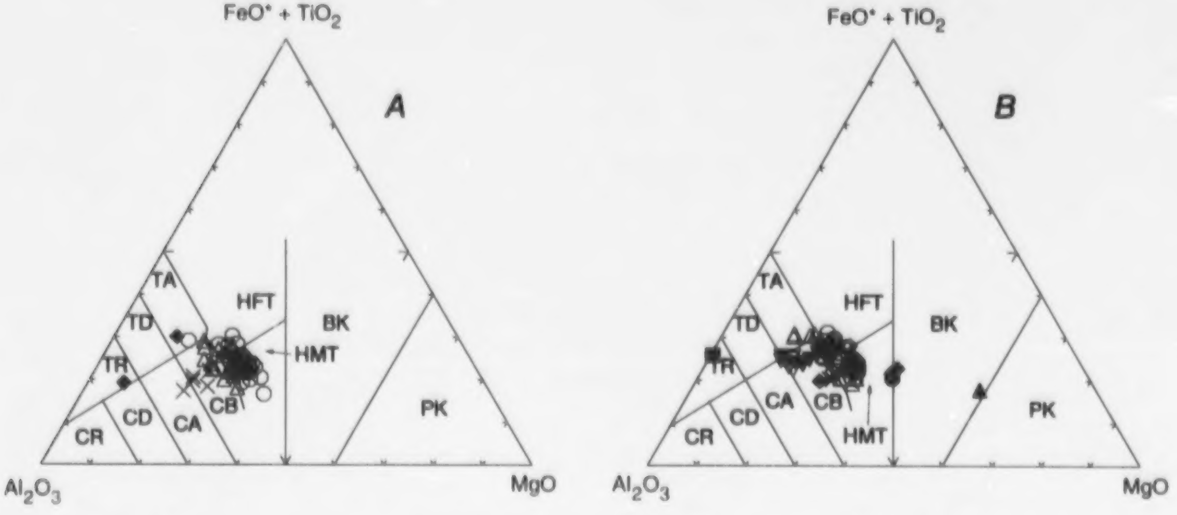


Figure 13. *AFM ternary (cation percent; Jensen, 1976) plot for selected non-boninitic Lushs Bight Group dykes and lavas (A—lavas, B—dykes). Data for modern boninites from Jenner (1981, 1982). HFT = high Fe tholeiite; HMT = high Mg tholeiite; BK = basaltic komatiite; PK = peridotitic komatiite; T = tholeiite; C = calc-alkaline. (A = andesite, B = basalt, D = dacite, R = rhyolite). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ▽—LOTI-F; *—BONINITE; ♦—CALC-ALKALIC BASALTS.*

ROCK CLASSIFICATION

This section attempts to identify the rock types (i.e., basalt, andesite, etc.) that occur in the Lushs Bight Group by using geochemical rock classification diagrams. For this purpose the data is plotted in three major groupings consisting of boninites, non-boninitic dykes and non-boninitic lavas. Both ICP-MS and TF-XRF data are used in the plots.

The boninites, both modern and from the Lushs Bight Group, fall mainly within the andesite and/or andesite—basalt fields (Figures 16 and 17). There is an overlap into the trachyandesite field on the Winchester and Floyd (1977) classifications diagram (Figure 17).

The majority of the non-boninite lavas and dykes straddle the sub-alkaline basalt and andesite—basalt fields (Figures 18 and 19). There is a substantial variation in the Nb/Y ratios; however, this variation is considered to be primarily a source-derived feature. However, the variation in SiO$_2$ illustrated in Figure 19, i.e., a near vertical trend of increasing SiO$_2$ at a constant Zr/TiO$_2$ ratio, is consistent with silica mobility. Silica can increase or decrease with alteration and it is likely then that this trend reflects both possibilities.

INTERPRETATION OF VARIATION DIAGRAMS

The major geochemical groups rather than the major rock types form the basis of discussion in this section because the rock types and/or stratigraphic units do not necessarily form consistent geochemical groups, for example, the different areas of sheeted dyke. Major elements, as defined for this report, are considered unstable during alteration (i.e., mobile) and are not discussed in this section (see discussion on alteration). Boninites and all other geochemical groups are generally plotted on the same diagram.

LFSE

The LFSE are mobile during alteration and it is difficult to compare the concentrations of many of the LFSE with those found in modern rocks. This may sometimes be further complicated by their petrogenesis. Nonetheless, it is instructive to look at the range in Na and K, the most abundant LFSE, utilizing the igneous spectrum plot of Hughes (1972). This diagram of Hughes (*op. cit.*) illustrates the changes in Na and K associated with spilitization. Boninites were not well documented and analyzed until the late 1970s and early 1980s (see Crawford *et al.*, 1989); hence, the "defined" igneous

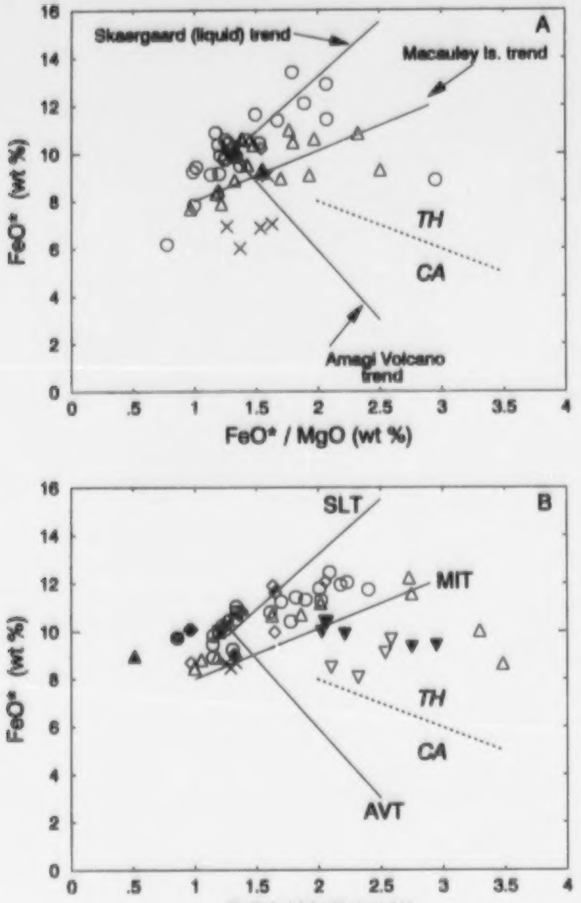


Figure 14. *Modified FeO* vs FeO*/MgO plot (Miyashiro, 1974) for selected non-boninitic Lushs Bight Group dykes and lavas (A—lavas, B—dykes). TH—tholeiitic trend, CA—calk-alkalic trend. ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS.*

spectrum field of Hughes (1972) does not include all of their range (Figure 20). The Lushs Bight Group boninites are depleted in K_2O and generally enriched in Na_2O + K_2O compared to modern boninites. Mean Na_2O in modern boninite rocks is about 1.2 percent, with none greater than 3.6 percent, while in Lushs Bight Group boninites there is a wide, equally distributed range from 0.2 to 5.4 percent. Mean K_2O in modern boninites is 0.45 percent, whereas the content in the Lushs Bight Group ranges from 0.1 to 1.5 percent. The alteration of the Lushs Bight Group boninites draws them towards the field of spilites.

The variation in the K_2O and Na_2O for the non-boninitic Lushs Bight Group rocks is shown in Figure 21. The low-K nature of the volcanism is reflected in this plot, but it is still clear that alteration has displaced the rocks upwards out of the primary igneous spectrum. As was observed by Swinden (1987) in the Wild Bight Group volcanic rocks, there is a greater tendency for the lavas to be displaced toward the spilite field. This is consistent with textural control of alteration, wherein the fine-grained to aphanitic pillow lavas are more altered than the coarser grained dykes.

Transition Elements

The strong positive correlation between Cr and Ni and the Mg# (Figures 22 and 23) is good evidence for their relative immobility during alteration. The Cr and Ni contents show a wide variation that is interpreted to be related to the degree of fractionation, i.e., Mg#. The high Cr and Ni contents of the boninitic lavas and dykes and the high Cr/Ni (>3) ratio are characteristic features of boninites (Jenner, 1981). The Ni content of the IAT group generally falls between 15 to 80 ppm, typical for rocks with this MgO content (cf. Gill, 1981). The Ti *vs* Cr ratios for the groups (Figure 24) are also typical of orogenic environments; the exception being the non-arc rocks (MORB), which plot within the ocean-floor basalt field. The CAB dykes contain the most surprising Cr and Ni contents, 500 and 100 ppm respectively, (Table 4, also see Table 5), which in conjunction with their relatively high Mg#, suggests they represent atypically primitive calc-alkalic basalt.

Both the boninitic lavas and dykes and the LOTI-F dykes are characterized by Ti/V ratios less than 10 (Figure 25). However, the majority of lavas and dykes in the LOTI, IAT and CAB groups are characterized by Ti/V ratios between 10 to 20, all typical of island-arc volcanic rocks. The MORB-like lava and dykes all have Ti/V >20, typical of non-arc tholeiitic volcanic rocks.

Th and HFSE

General aspects of the variation in Th and HFSE are illustrated in a series of tectonic discrimination diagrams (Figures 26 to 29). Both the boninitic lavas and dykes plot outside any of the tectonic environments on the Ti - Zr and Zr/Y *vs* Zr diagrams, reflecting both their extremely depleted nature and their high and variable Zr/Y ratios. On the Ti—Zr—Y plot (Figure 28), the boninites fall predominantly in the calc-alkalic basalt field.

Both the IAT and LOTI groups plot within or near the island-arc tholeiite field on all the tectonic discrimination plots in Figures 26 to 28. The non-arc MORB group is distinct from the boninites, LOTI and IAT on the Ti/Zr plot, where it plots distinctly in the ocean-floor basalt

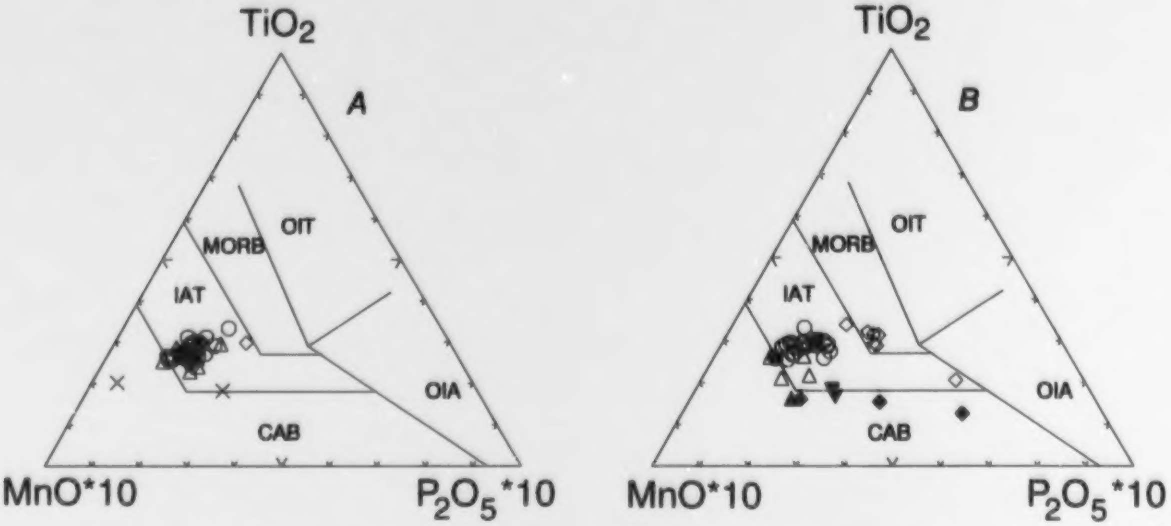


Figure 15. *MnO—TiO_2—P_2O_5 discriminant plot (after Mullen, 1983) for non-boninitic Lushs Bight Group lavas and dykes (A—lavas, B—dykes). OIT—ocean-island tholeiites, OIA—ocean-island basalts, MORB—mid-ocean ridge tholeiites, IAT—island-arc tholeiites, CAB—calc-alkalic basalts. (Note: Plots were screened for samples with silica content between 45 and 54 percent.) ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS.*

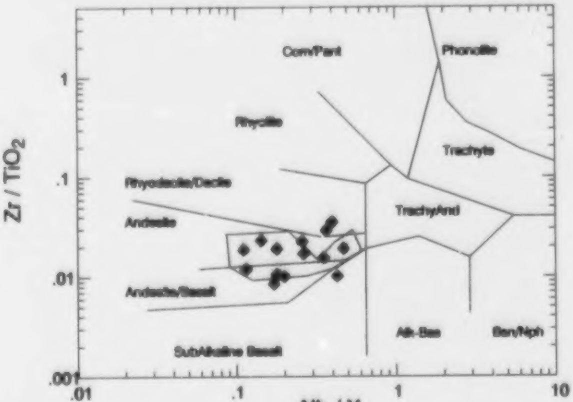


Figure 16. *Zr/TiO_2 vs Nb/Y diagram (Winchester and Floyd, 1977) for Lushs Bight Group boninites. Stippled area is field of modern-day boninites.*

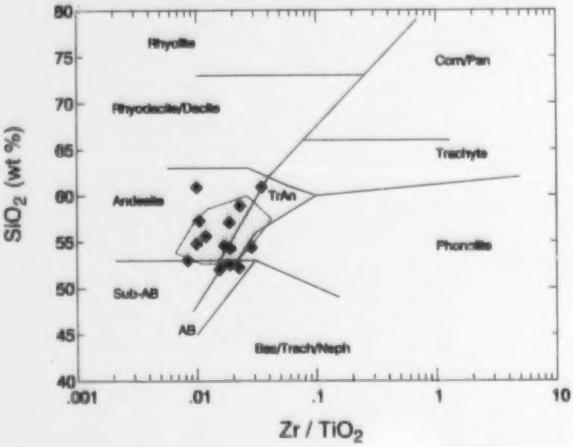


Figure 17. *Zr/TiO_2 vs SiO_2 diagram (Winchester and Floyd, 1977) for Lushs Bight Group boninites. Stippled area is field of modern-day boninites.*

field, it is less distinct on the Zr/Y *vs* Zr and overlaps considerably on the Ti—Zr—Y plot. Because of their depleted or primitive nature, the CAB dykes are not uniquely defined as calc-alkalic on any of these discrimination plots.

Swinden *et al.* (1989) devised the discrimination plot Nb/Th *vs* Y to discriminate between arc and non-arc rocks (Figure 29). The hatched field about the Nb/Th primitive mantle ratio of ~7.4 schematically illustrates a zone of transition between arc and non-arc signatures. A transition in geochemical signature is expected for the following reasons: i) at the low concentrations of Nb and Th found in many oceanic basalts, resolution of the arc-signature (i.e., nagative Nb with respect to Th) will be difficult. Thus only high-quality data should be used in this plot; and ii) since the arc signature reflects mixing of different components, a complete range of variation can be

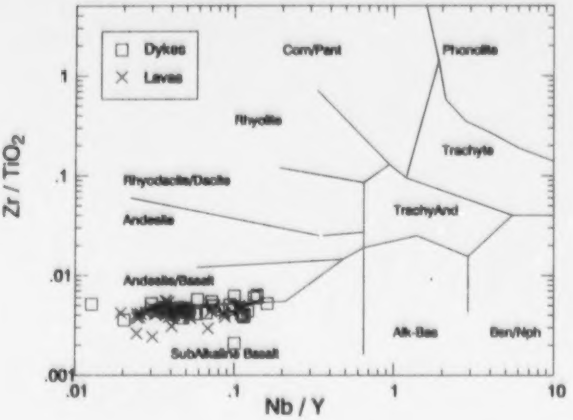


Figure 18. *Zr/TiO$_2$ vs Nb/Y diagram (Winchester and Floyd, 1977) for selected non-boninitic Lushs Bight Group dykes and lavas.*

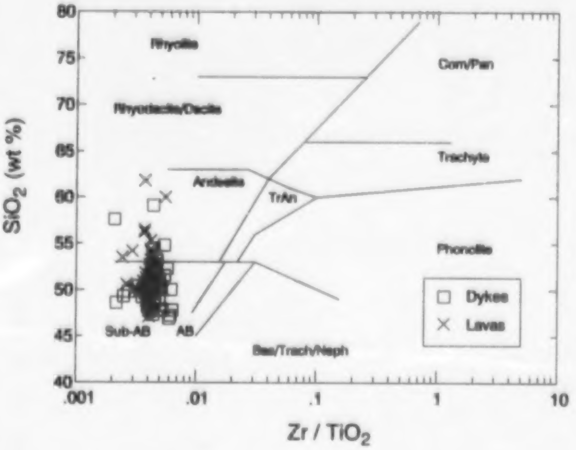


Figure 19. *Zr/TiO$_2$ vs SiO$_2$ diagram (Winchester and Floyd, 1977) for selected non-boninitic Lushs Bight Group dykes and lavas.*

expected. Not all of the data used in Figure 10 is plotted because there are either no Th analyses or reliable Th analyses available. (Note there are no non-arc (MORB) dykes plotted.) The boninites, LOTI rocks and 2 of the 3 CAB dykes are characterized as refractory arc (RARC) on the diagram, The majority of the IAT group has a clear arc geochemical signature. Note that the three IAT lavas plotting in the non-arc field have Y contents similar to the other IAT, (i.e., significantly lower than that found in the MORB-like rocks) and are also indistinguishable on HFSE discriminant diagrams from the IAT group.

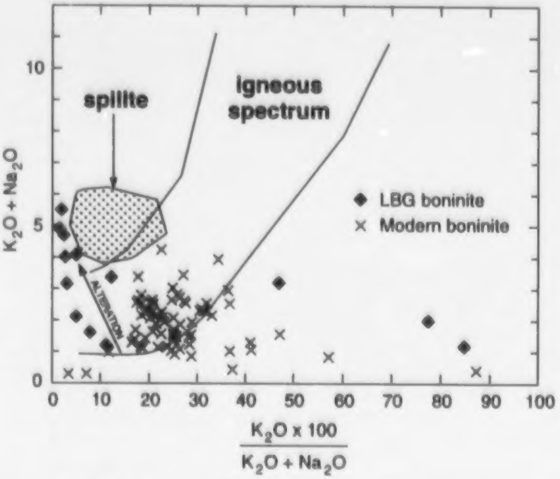


Figure 20. *Modified Hughes (1972) plot illustrating Na and K changes during formation of spilites and alteration of boninites. Lushs Bight Group boninites and modern boninites are solid diamonds and crosses, respectively. (Data source for modern boninites is Jenner, 1981, 1982).*

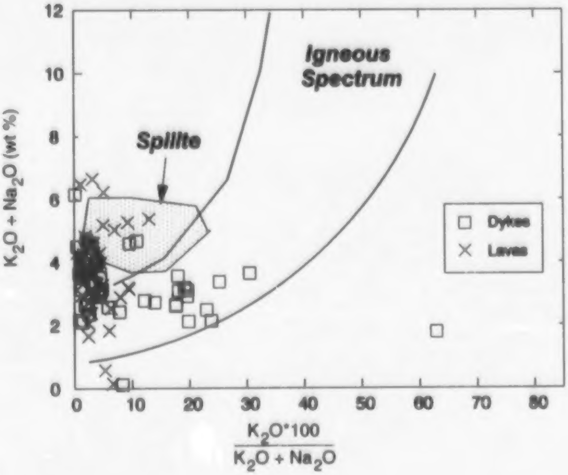


Figure 21. *Modified Hughes (1972) plot illustrating Na and K changes during formation of spilites and alteration of selected Lushs Bight Group dykes and lavas. Note that the lavas are generally more highly altered than the dykes.*

REE

To illustrate the wide variety and complexity of REE patterns in the Lushs Bight Group, the ICP-MS analyses of individual samples are presented as a series of extended

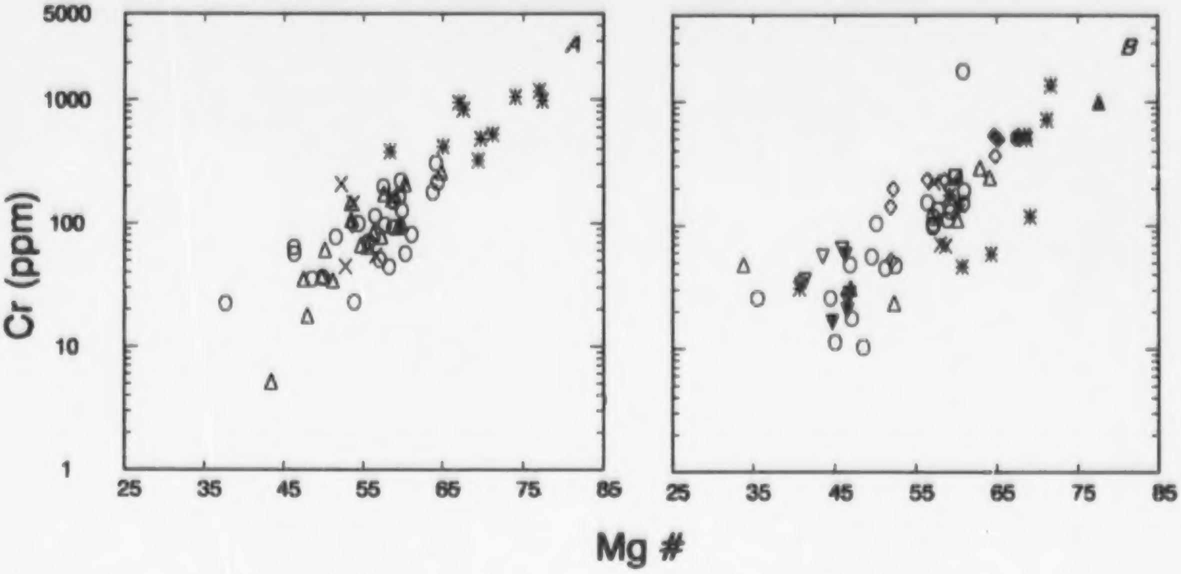


Figure 22. *Log Cr vs Mg#, Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; O—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure.*

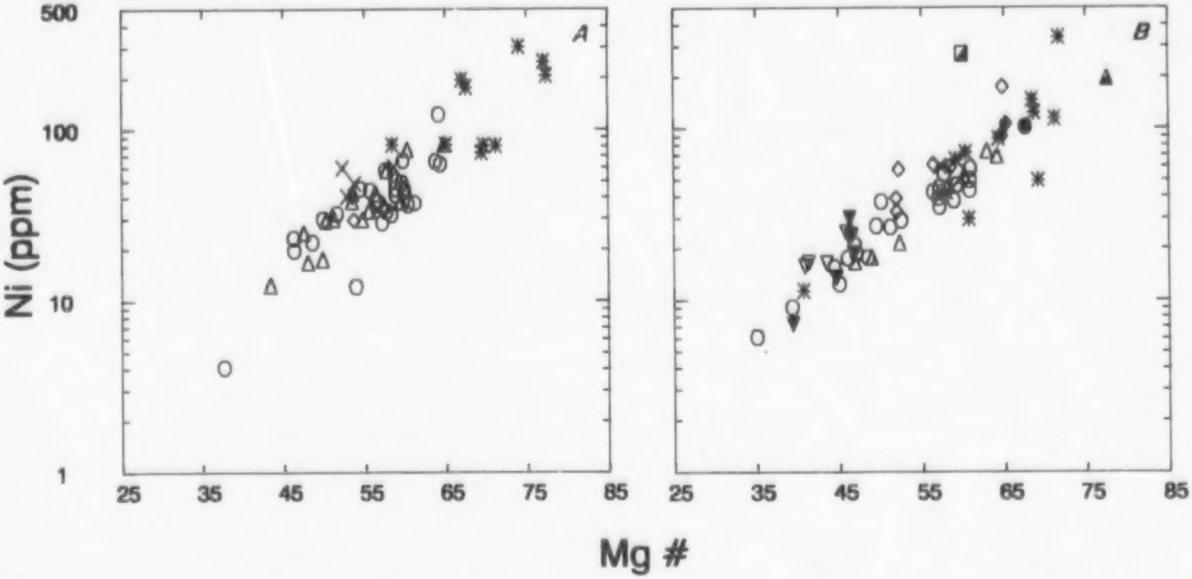


Figure 23. *Log Ni vs Mg#, Lushs Bight Group (A—lavas, B—dykes). ◇--Non-ARC; O—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure.*

REE plots, often with subsets selected on the basis of the Mg# range. Representative fields for the geochemical groups of lavas have been compiled using both the ICP-MS and TF-XRF data. Normalizing values for these plots are primative mantle values from Hofman (1988).

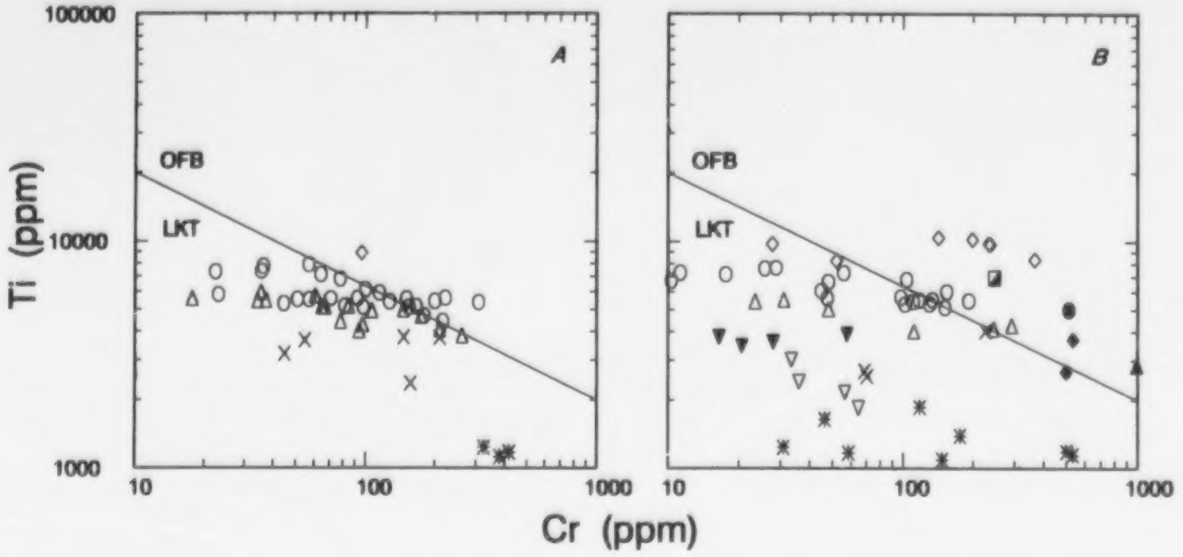


Figure 24. *Ti vs Cr discriminant diagram, Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ▽—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. LKT—low-potasium tholeiites, OFB—ocean floor basalts. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure.*

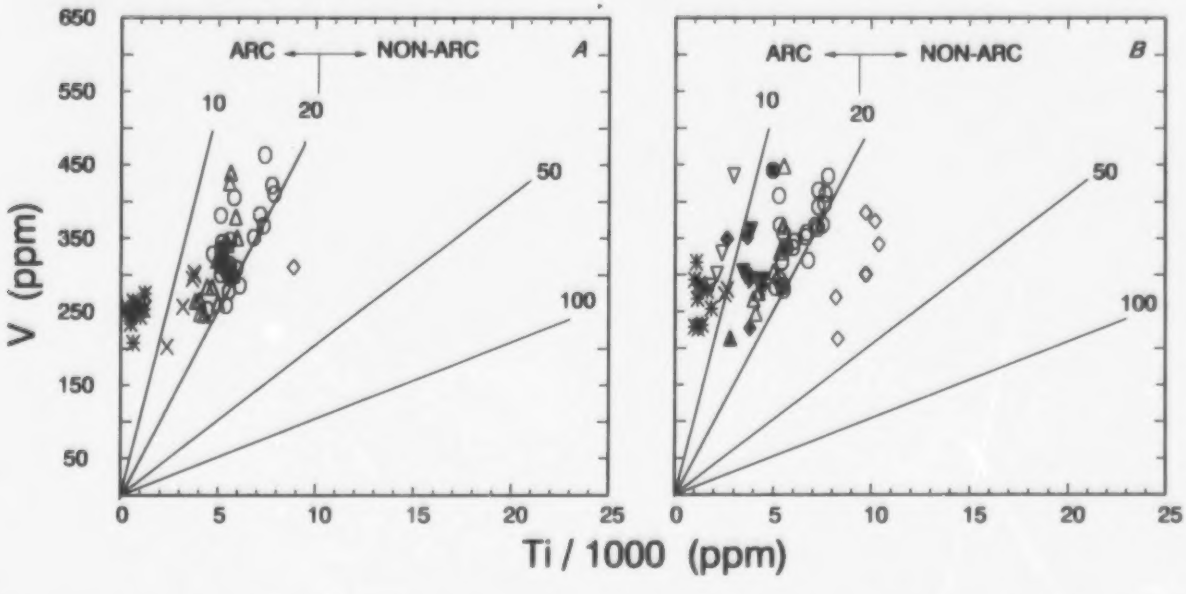


Figure 25. *Ti vs V discriminant diagram (Shervais, 1982), Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ▽—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Lines represent constant Ti/V ratios. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. The felsite or epidosite dyke shown in Table 4 and shown as ■ on some plots does not plot on this figure.*

Lavas

The extended REE pattern for the boninitic rocks is characterized by Th enrichment relative to La, positive Zr relative to Sm and Nd, and a concave pattern with MREE depletion relative to LREE and HREE (Figure 30). Generally, there is a negative Nb anomaly relative to Th and La. Samples 1543336 and 1543337 do not show this

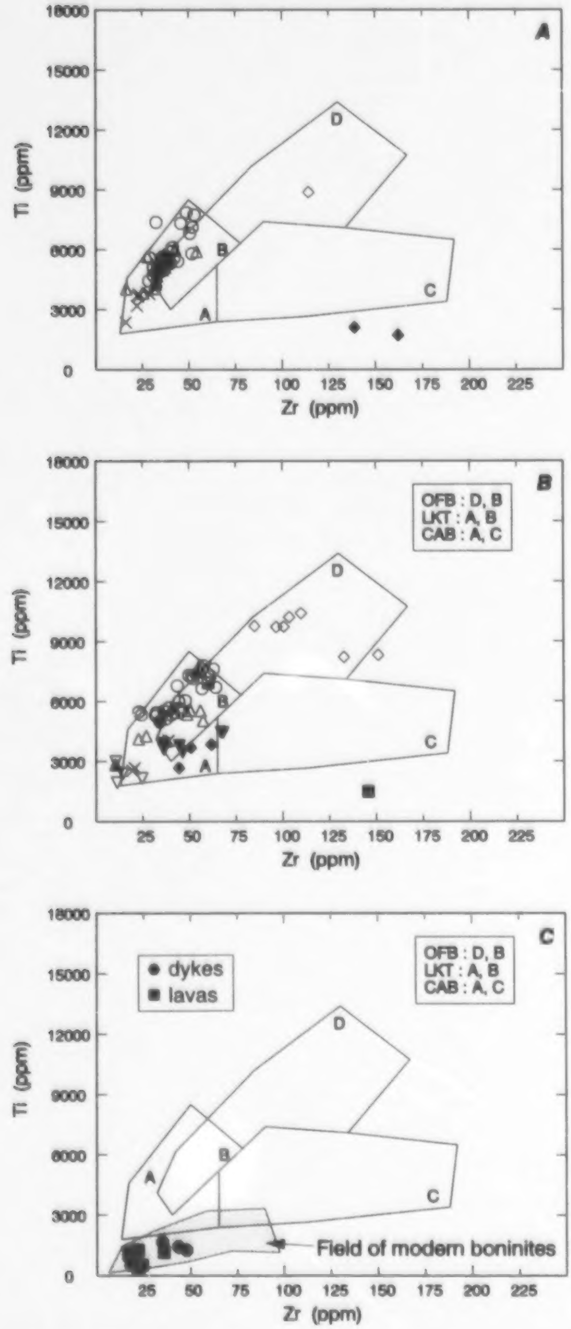


Figure 26. *Ti vs Zr discriminant diagram (Pearce and Cann, 1973), Lushs Bight Group (A—lavas, B—dykes, C—boninites). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings.*

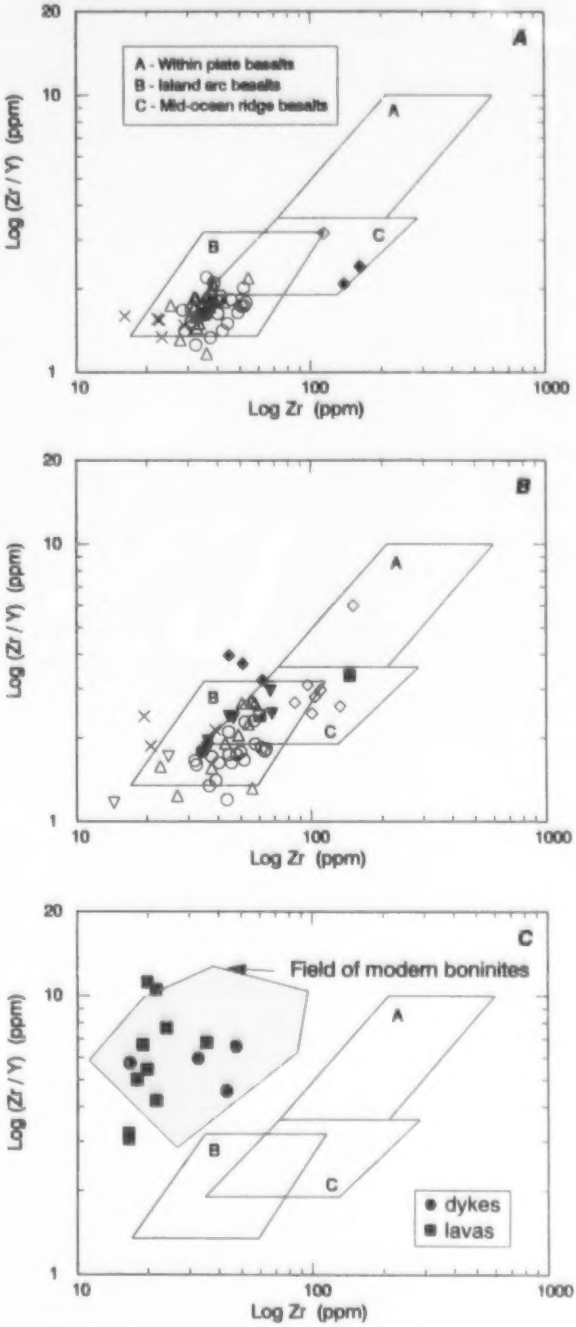
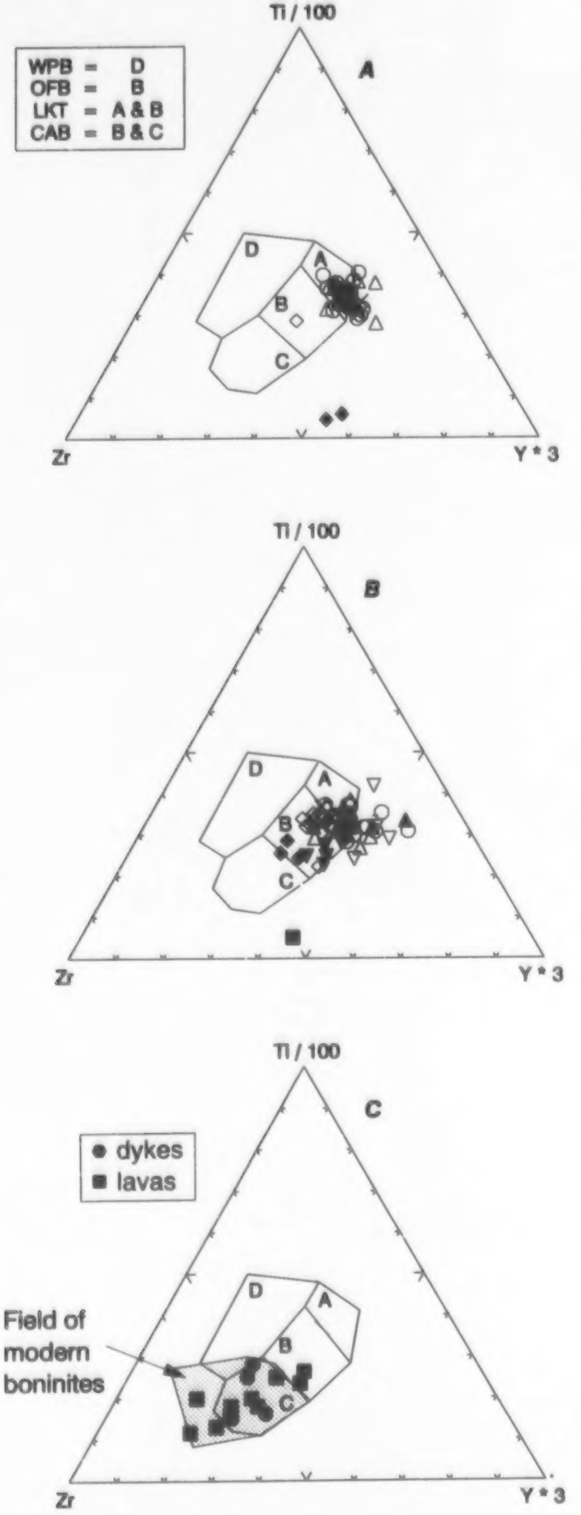


Figure 27. *Zr/Y vs Zr discriminant diagram (Pearce and Norry, 1974), Lushs Bight Group (A—lavas, B—dykes, C—boninites). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings.*



anomaly and are overall depleted in REE. Many samples show crosscutting patterns and heterogenities in abundances relative to Mg#. Some samples having parallel patterns could be related by low-pressure fractionation of the appropriate liquidus phases, presumably olivine ± orthopyroxene (Jenner, 1981, 1982) e.g., samples 1543329, 1543365 and 1543334. Samples 1543335 and 1552118 have Mg#s of about 67, and their pattern is consistent in shape and abundance with that present for the more primitive boninites. Sample 1543347, the least primitive boninite (Mg#58), has a similar pattern and abundances to that observed in most of the other boninites.

There is considerable variation in REE abundances and patterns in the IAT group (Figure 31). The following features are noteworthy: i) Type I are generally the most depleted, particularly in HREE, ii) all of the samples have negative Nb with respect to Th, but Th is not necessarily enriched relative to La, iii) Ti and Y behaviour is consistent with that of the REE, while Zr can be depleted relative to Nd—Sm, iv) all samples exhibit LREE depletion, and the patterns are often crosscutting either in LREE or HREE, and v) overall there is a slight increase in REE and HFSE with fractionation. This is consistent with a low pressure fractional crystallization of olivine ± clinopyroxene ± plagioclase as likely phases.

The variability in abundance of REE and in pattern shape within the IAT is well illustrated in Figure 32. The subdivision into Type I and II based on Mg# and Ti (see Figure 10) oversimplifies the chemical diversity of this group, particularly with regards to Th, Nb and the LREE. Both the trace elements and REE for the IAT group suggest that their extended REE pattern for any given set of Mg#s is a combination of source-derived characteristics and low pressure fractional crystallization.

The LOTI group is enriched in HREE relative to the boninites (see Figure 32), is overall LREE depleted and lacks evidence for positive Zr relative to Nd and Sm (Figure 33), possibly linking their petrogenesis more to the IAT lavas. Compared to the IAT lavas in the Mg# 50-59 range (see Figure 32), there is some similarity in Th through Nd, but they are depleted with respect to Zr through Lu. All the patterns have negative Nb with respect to Th.

Figure 28. *Ti—Zr—Y discriminant diagram (Pearce and Cann, 1973), Lushs Bight Group (A—lavas, B—dykes, C—boninites). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ▽—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings.*

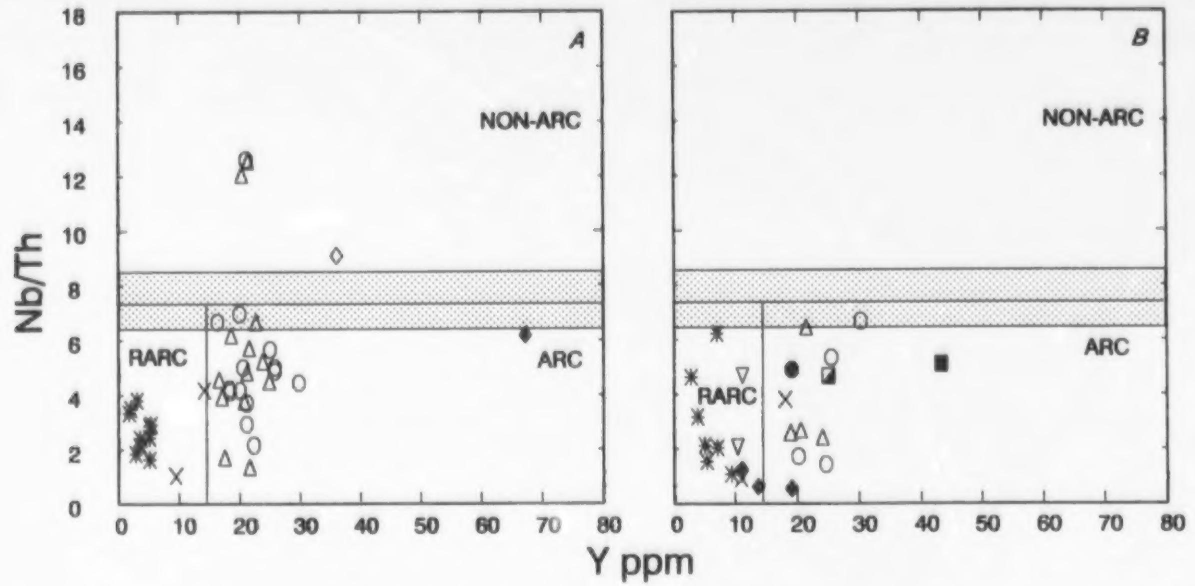


Figure 29. *Nb/Th vs Y discriminant diagram (Swinden* et al., *1989), Lushs Bight Group (A—lavas, B—dykes). ◇—Non-ARC; ○—IAT TYPE II; Δ—IAT TYPE I; X—LOTI; ▼—LOTI-FH; ∇—LOTI-F; *—BONINITE; ◆—CALC-ALKALIC BASALTS. Samples 1542099 (◪), 1542236 (●) and 1542289 (▲) are all dykes that do not really conform to the chemical groupings. Samples in the non-arc field are 1543344, 1542013, 1542027 and 1542034.*

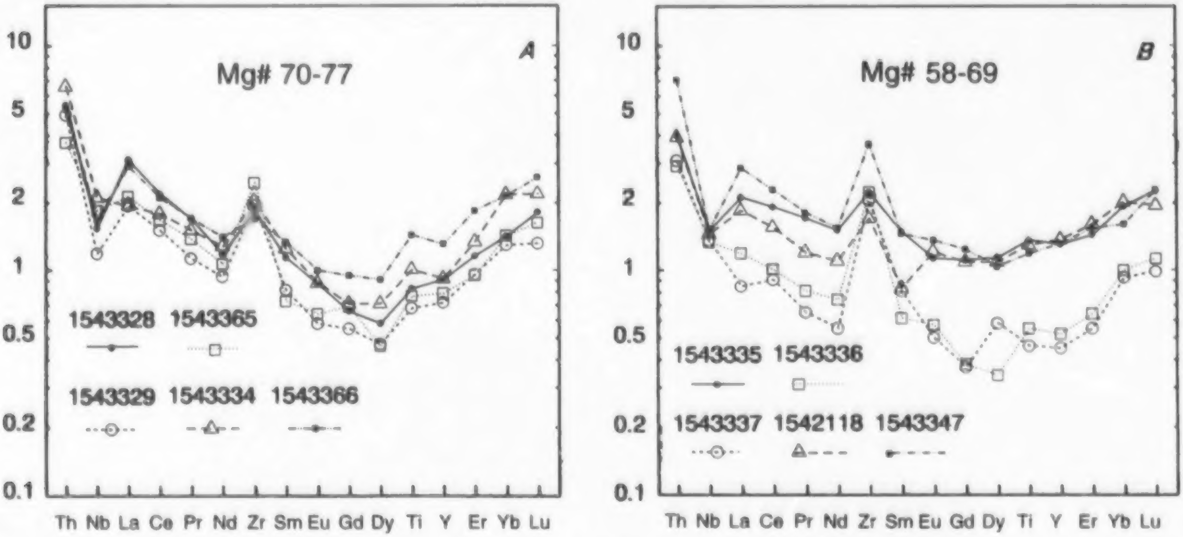


Figure 30. *Primitive mantle normalized extended REE patterns for boninitic rocks of the Lushs Bight Group (A—Mg# 70-77; B—Mg# 58-69).*

The lava classified as a MORB (sample 1543344) on most of the discriminant diagrams is characterized by the lack of a well defined negative Nb anomaly and overall low HFSE and REE abundances (Figure 34). It is part of a black, hematitic (generally more chlorite-rich than epidote-rich), pillow basalt phase that in places marks the top of the Lushs Bight Group near the contact with the Western Arm Group in the Clam Pond area. The other

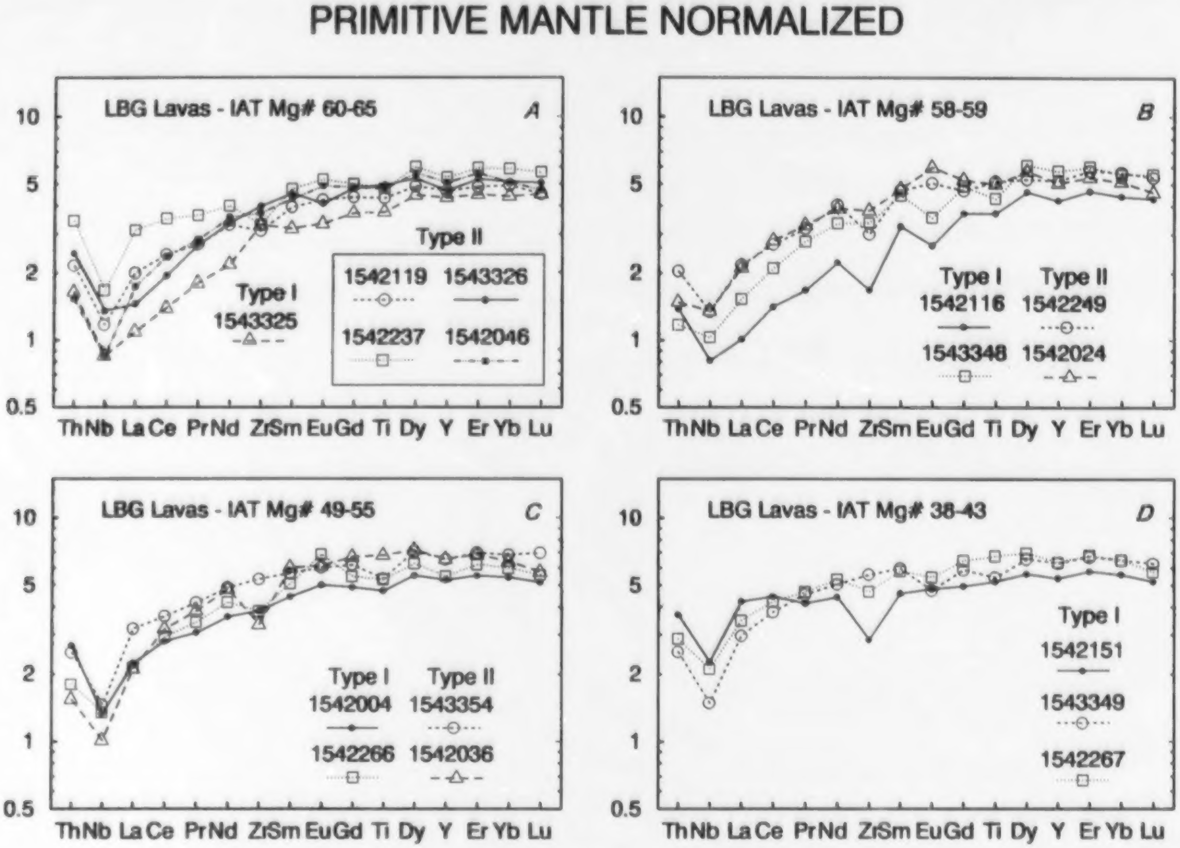


Figure 31. *Primitive mantle normalized extended REE patterns for IAT lavas, Lushs Bight Group.*

three lava samples were distinguished as non-arc only on the Nb/Th vs Y diagram. They all come from the Southern Arm area and are all intruded by IAT group dykes. They are LREE-depleted and with the exception of a negative Nb anomaly, have concentrations of REE and HFSE similar to most of the island-arc tholeiites, i.e., much lower than MORB.

Dykes

Extended REE patterns for Lushs Bight Group dykes are given in Figure 35. The boninitic dykes are characterized by Th enrichment relative to Nb and La, by negative Nb anomalies, by concave REE patterns and enrichment in Zr relative to Nd and Sm. Sample 1542206 is the most primitive sample (see Table 4) and is characterized by lower abundance of all elements except Nb. Samples 1543332 and 1543345 have similar Mg#, but the latter sample is enriched in all elements, excluding Ti, by a factor of 1.3 to ~2. The dykes are enriched in LREE and Th relative to the lavas.

The dykes of the IAT and LOTI groups have a large range in Mg#, thus making detailed comparisons difficult. In general, both these groups are LREE depleted, and there is considerable variation in Th, Nb, La. All have negative Nb, but not all have Th enrichment. The LOTI sample and IAT-II sample 1542097 have similar Mg#s, and are quite similar in La and Nb. They differ most in elements less compatible than Nd (i.e., Nd—Lu) and the LOTI sample has a Th enrichment compared to sample 1542097. The IAT-II samples have essentially parallel patterns, with the least primitive sample having the higher element abundances. This is consistent with a low-pressure fractional crystallization petrogenesis. Patterns in the IAT-I group samples crosscut each other, the most notable example being shown by the LREE enrichment in sample 1543352. The IAT-I samples are depleted in HREE, Ti and Y relative to the more primitive IAT-II group (see Mg#s in Table 4). IAT-I sample 1543352, however, is enriched in Th, Nb, LREE and Zr relative to the most primitive IAT-II sample (1542097).

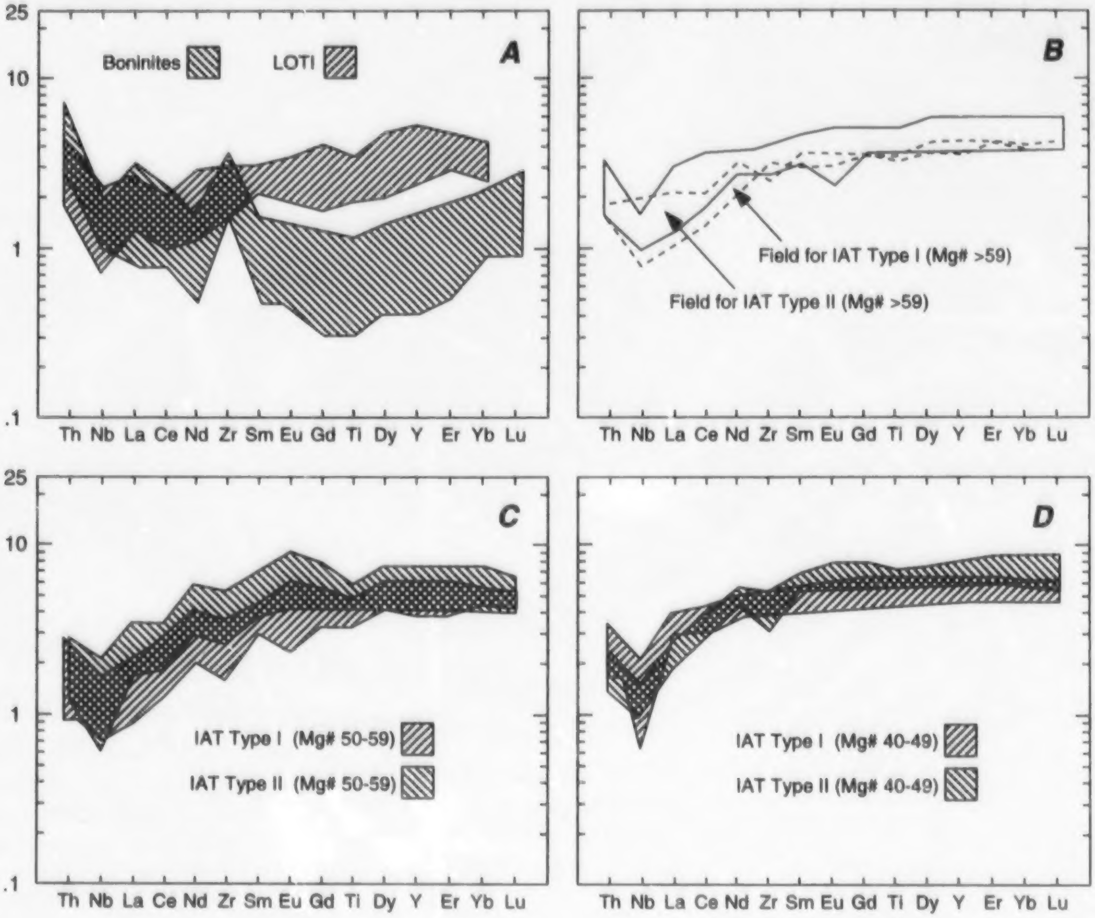


Figure 32. *REE-pattern fields for the different Lushs Bight Group lava groups (combined ICP-MS and TF-XRF data).*

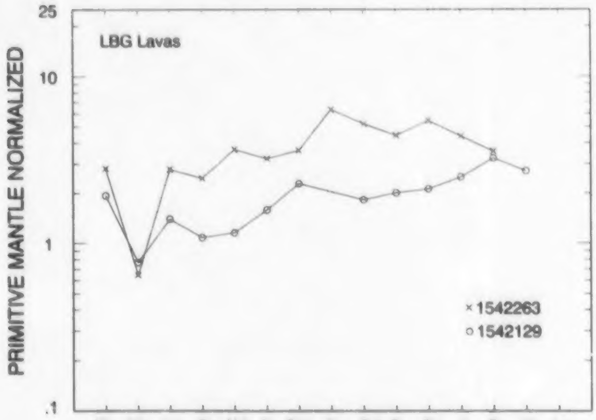


Figure 33. *Primitive mantle normalized extended REE patterns for LOTI lavas, Lushs Bight Group.*

The calc-alkalic dykes, all intrusive into the boninitic lavas, are characterized by Th enrichment relative to La,by well developed negative Nb anomalies, and by LREE enrichment. Samples 1543338 and 1543333 have slight negative Zr anomalies and the latter also has a negative Ti anomaly. They have similar high Mg# and Cr and Ni contents, but show considerable variation in Th, LREE, Ti and Zr abundances. Considering their overall chemical similarity, these samples could represent either magmas derived from a heterogeneous source, or by different degrees of partial melting of the source. In the latter case, sample 1543338 would represent a smaller degree of partial melting and sample 1543333 could possibly be derived from sample 1543338 by low-pressure fractional crystallization.

There is no REE data available for the non-arc (MORB) dykes.

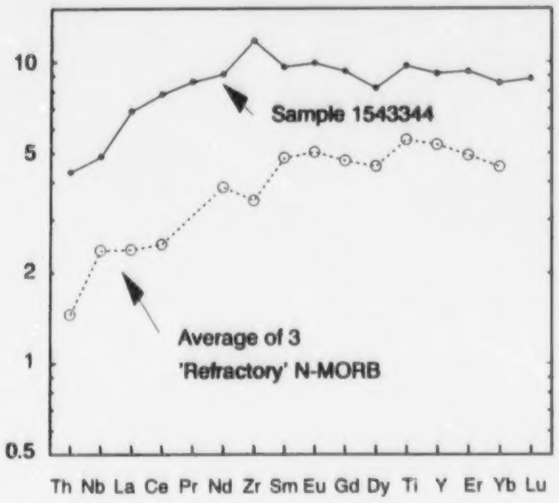


Figure 34. *Primitive mantle normalized extended REE pattern for Lushs Bight Group non-arc lavas. The three samples averaged are 1542013, 1542027 and 1542034.*

Felsic Rocks

Two samples of Lushs Bight Group felsic rocks were analysed for REE and Th (Figure 36). Sample 1543362 is a felsic volcanic characterized by i) abundances of REE 15 to 20 times primitive mantle, ii) LREE depletion, iii) strong negative Eu anomaly, and iv) a negative Nb anomaly. The major- and trace-element characteristics of this sample indicate that it could be derived by low-pressure fractional crystallization.

Sample 1543359 is from an altered, epidotized dyke, which is interpreted to cut boninitic dykes near Springdale. It is characterized by low REE concentrations in the order of 5 to 12 times primitive mantle, by LREE depletion, by a negative Nb anomaly and by a positive Zr anomaly. The petrogenesis of this rock is unclear, but it could be an altered andesite—dacite dyke with affinities to LOTI or IAT-I.

Sm—Nd Isotopes

To augment the trace-element data and provide a representative suite for a regional isotopic study, Sm—Nd isotopic compositions were determined on 11 samples from the Lushs Bight Group (Table 6).

The three boninite samples range in initial isotopic composition ($\epsilon\text{Nd}_{(T)}$) from +2.8 to -0.3. This range in isotopic composition is positively correlated with ^{147}Sm/^{144}Nd, and overlaps with other Newfoundland boninites (Figure 37). It is consistent with the addition of an enriched component to a depleted mantle source.

The eight non-boninitic Lushs Bight Group samples are all from the IAT group and have $\epsilon\text{Nd}_{(T)}$ values ranging from +7.7 to +2.5, with the lowest value occurring in sample 1542116. The low $\epsilon\text{Nd}_{(T)}$ and high ^{147}Sm/^{144}Nd in 1542116 places it in the refractory arc volcanic field (RARC). The remaining seven samples have two distinct clusterings made up of a group of four samples (1542024, 1542249, 1542267, 1542151) with $\epsilon\text{Nd}_{(T)}$ ranging from +6.5 to +7.7 and a second group of three samples (1542004, 1542036, 1542266) with values from +5.5 to +6.2. Both of these clusters contain samples from both Type I and II of the IAT group. Six out of the above seven samples plot within island-arc tholeiite fields defined by all Newfoundland Ordovician volcanic rocks and are characterized by Nb/Th ratios of ~5. One sample (1542024) has a Nb/Th ratio of 6.7 and plots in the arc-transitional-MORB field (ATM).

Summary

Hydrothermal alteration and metamorphism of oceanic basalts can lead to substantial changes in their chemical composition. As an element group the LFSE are more susceptible to alteration, than the HFSE, REE, TE and some major elements. A subset of the LFSE (K, Na, Ca, Cs, Rb, U and Pb) should be considered mobile and not used in classifying the primary igneous characteristics of altered volcanic rocks, or in defining the tectonic environment of formation. However, Mn and Th, particularly Th, are immobile or often only slightly mobile, and in conjunction with HFSE are useful in defining rock types and environments of formation. The TiO_2—P_2O_5—MnO plot devised by Mullen (1983) appears to work well.

However, there is less evidence to support significant mobility of the HFSE, TE, and REE. It is important to reiterate that the use of the term "significant mobility" means that while elements may have undergone some degree of mobilization, they have done so in a coherent manner which does not preclude recognition of their original source-derived characteristics. The mobility of TE, REE and HFSE and Mn and Th is normally most significant in the presumably fine-grained and depleted boninites. In general, when elements in these element-groupings are mobile, the patterns on extended REE plots clearly indicate this (Dunning *et al.*, 1991). There may, however, be more subtle variations that are not detected or obvious, for example in the LREE. However, the REE, Th and HFSE are consistent with that observed in equivalent modern settings and with Sm—Nd isotopic values (Swinden *et al.*, 1990; Jenner *et al.*, 1991).

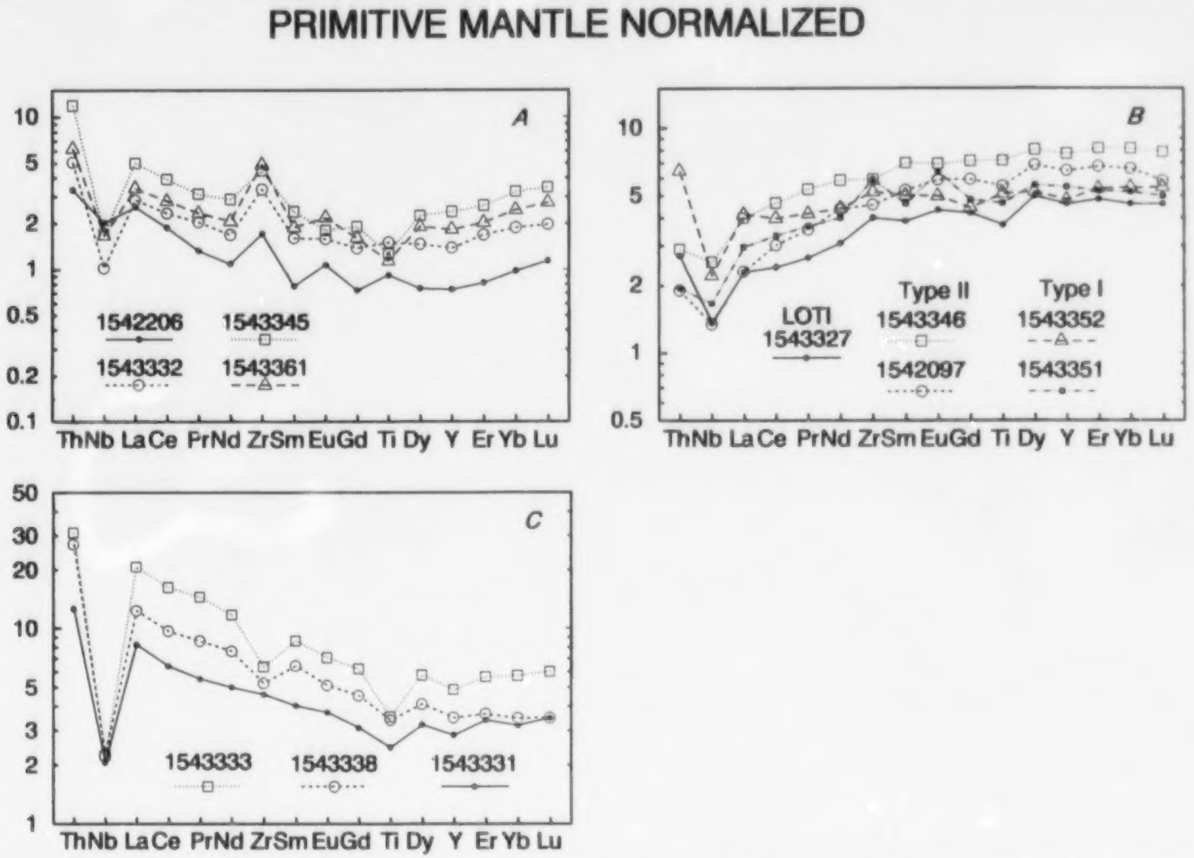


Figure 35. *Primitive mantle normalized extended REE patterns for Lushs Bight Group dykes (A—boninites, B—IAT (type I and II) and LOTI, C—CAB).*

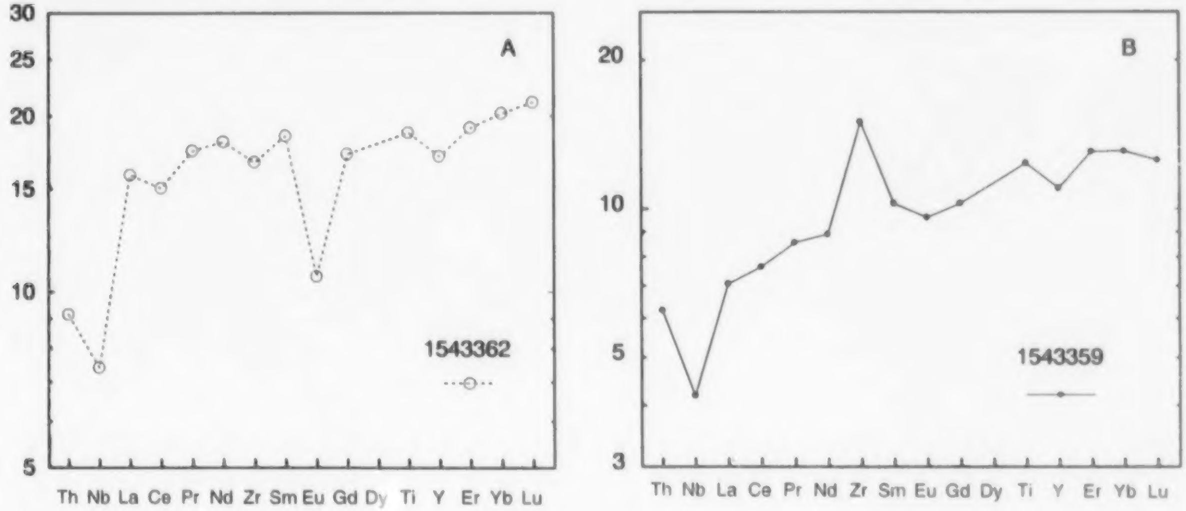


Figure 36. *Primitive mantle extended REE patterns for felsic rocks, Lushs Bight Group (A—felsic volcanic, B—felsite-epidosite dyke).*

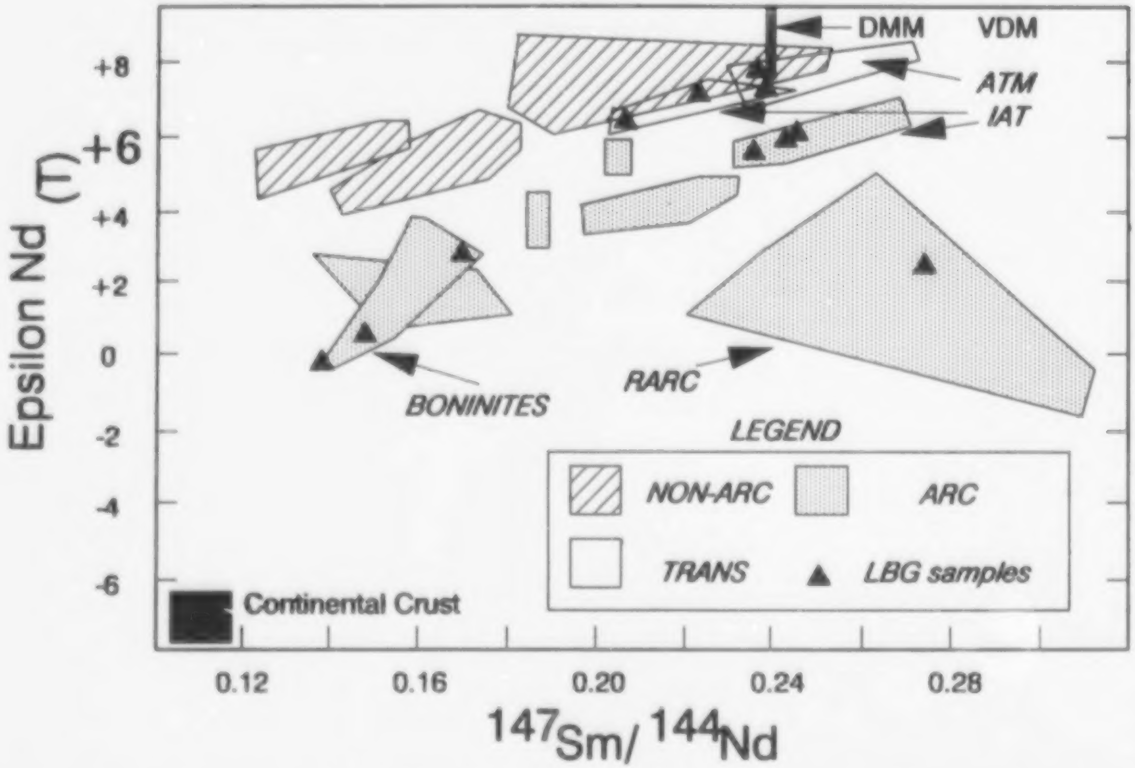


Figure 37. *Sm—Nd isotopic data for the Lushs Bight Group and comparison with other Ordovician Newfoundland volcanic rocks. Non-arc and arc fields based on about 80 isotopic determinations and ICP-MS analyses from volcanic rocks in ophiolites and volcano-sedimentary sequences throughout central Newfoundland (Jenner* et al., *1990; Swinden* et al., *1990). DMM = depleted MORB mantle (based on range for N-MORB today, White, 1985; von Drach* et al., *1986), VDM = very depleted mantle, estimated extreme for depleted mantle. IAT, ATM, BONINITE and RARC fields correspond to our range for island-arc tholeiites, arc-transitional-MORB, boninitic and refractory arc-volcanic rocks. Continental crust field based on average present day value of εNd = -16 and average upper continental crust composition (Taylor and McLennan, 1985).*

There are three major geochemical groups within the Lushs Bight Group that are common to both the lavas and dykes. They are boninites, island-arc tholeiites, and low-Ti tholeiites (LOTI). There are also small groups of non-arc (MORB) lavas and dykes and calc-alkalic (CAB) dykes. Heterogeneities with regard to major, trace and isotopic compositions exist in all of the groups.

All of the geochemical groups show mobility of the LFSE such as K, Na and probably Ba. The non-boninitic rocks show some evidence of major-element mobility, particularly with regard to SiO_2 and FeO*/MgO relative to Al_2O_3. The relative mobility of FeO* and MgO probably causes some scatter and/or change in FeO*/MgO ratios. However, the changes are not, in general, great enough to preclude use of this or similarly based fractionation indicators, especially in light of HFSE heterogeneity in the Lushs Bight Group volcanic rocks. However, the element concentrations and variations observed in the boninites are similar to modern day ones, indicating that they have not undergone significant modification of their major element characteristics. The transition elements (TE), HFSE, Th and REE appear to have been stable or at least behaved coherently for all the geochemical groups. They are used in identifying the tectonic environment of the Lushs Bight Group.

Basalt and basaltic-andesite are the dominant rock types, however, minor felsic rocks (rhyodacite—rhyolite) are present. The boninites are dominantly high-Mg andesites and andesite-basalt with high Cr and Ni and low Ti. In some cases, they may represent primary or primitive mantle-derived melts. The geochemical analogies with modern and ancient boninites suggest that these rocks could have been clinoenstatite-bearing; however, primary minerals and textures have been destroyed. The IAT are

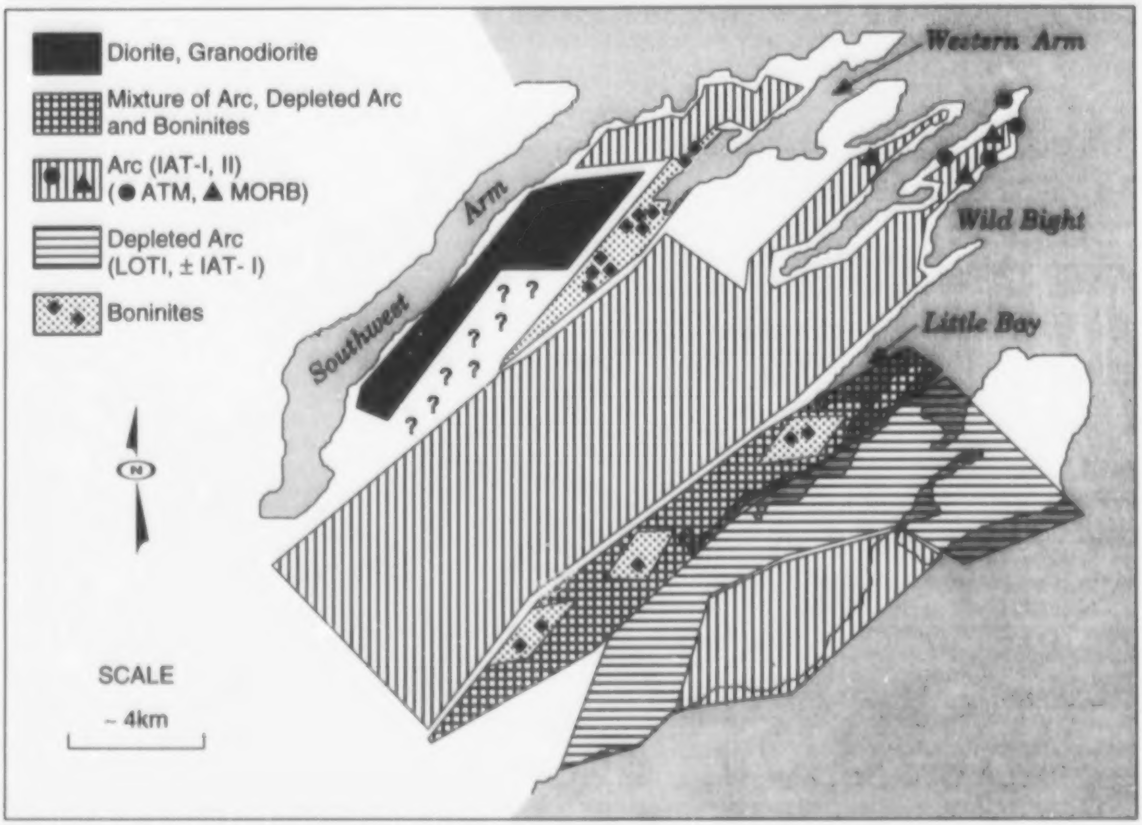

Diorite, Granodiorite
Mixture of Arc, Depleted Arc and Boninites
Arc (IAT-I, II) (● ATM, ▲ MORB)
Depleted Arc (LOTI, ± IAT- I)
Boninites
N
SCALE
~ 4km
Western Arm
Wild Bight
Little Bay
Southwest Arm
? ?
? ?
? ?
? ?
? ?

Figure 38. *Schematic map illustrating the distribution of the geochemical groups within the Lushs Bight Group (see text for explanation).*

areally the most extensive geochemical group. They have Ni, Cr and Ti *vs* Cr, HFSE and REE typical of orogenic environments. The LOTI group is intermediate between the IAT and boninites with respect to Mg# and Ti content. However, the petrogenesis of these rocks seems more clearly linked to the IAT.

Whereas there are marked similarities in chemistry between the lavas and dykes, significant differences are also present. The dykes contain a number of low-Ti and low Mg# rocks, referred to as LOTI-FH and LOTI-F, that are not present in the lavas. A distinct group of dykes (CAB) with calc-alkalic tendencies, primitive magma characteristics (high Mg#, Cr and Ni) and LREE enrichment cut the boninitic lavas south of Western Arm. These dykes could be related to the Cooper's Cove and Colchester plutons, which also intrude the Lushs Bight Group. The rocks are similar to the high-Mg andesites—sanukitoids described by Tatsumi and Ishizaka (1981, 1982) and are interpreted as primary andesitic magmas.

The non-arc or MORB-like rocks are characterized by high TiO_2, by Ti/V ratios > 20, by Nb/Th ratios > 8.2. These are all indicative of a non-arc tectonic environment. The dykes have a wide geographic distribution within the Lushs Bight Group area, whereas the lava (basalt) occurs at the top of the Lushs Bight Group near the contact with the overlying Western Arm Group.

SPATIAL RELATIONSHIPS OF THE GEOCHEMICAL GROUPS

Spatial relationships between the different geochemical groups are illustrated schematically in Figure 38. The geochemical group distribution map was drawn using the following procedures: i) compilation of all available geochemical data, ii) construction of a map showing only lava geochemistry, iii) identification of areas of concentrations of particular geochemical groups of lava, iv) integration of dyke data into the map, and wherever possible, crosscutting relationships between geochemical types was established, and v) comparisons with geochemical data on volcanics in other groups and intrusive bodies. The maps distribution pattern in Figure

38 may include one or more geochemical groups, or parts thereof, because of the spatial component. It should be noted that in general there appears to be no correlation between geochemical grouping and the two metamorphic facies (i.e., main and black, discussed in the section on Structure and Metamorphism) found in the Lushs Bight Group, except for the MORB-like lava at the top of the Lushs Bight Group near the Western Arm Group contact.

Boninitic rocks are restricted to two linear belts, southwest of Western Arm and southwest of Little Bay, respectively (Figure 38). Deformed and undeformed boninitic pillow lavas cut by boninitic dykes form a relatively continuous zone of outcrop in the Western Arm area. Calc-alkalic (CAB) dykes are also extensive in this area. The area indicated by question marks on Figure 38, indicates that insufficient sampling and analytical data are available to enable characterization. In the Little Bay area, boninitic lavas and dykes occur as a discontinuous belt extending from the Little Bay Mine area to Davis Brook. This area consists of fault-bounded blocks of lavas and dykes but the samples from any given block tend to form a consistent geochemical group. Boninitic dykes have not been documented to cut rocks of depleted arc (LOTI) or arc (IAT, ATM, MORB) affinity, although in the sheeted diabase dyke unit north of Lady Pond there are ambiguous intrusive relationships between boninitic and IAT-II dykes. A dyke of LOTI affinity cuts boninites in the Little Bay area. In the Western Arm and Little Bay areas dykes of calc-alkalic and MORB affinity cut the boninites.

The IAT group Types I and II, is referred to as the 'arc group'; Types I and II could not be spatially separated. The 'arc-group' rocks underlie the central part of the Springdale Peninsula, an area west of Western Arm and an area northeast of Springdale. Arc rocks transitional to MORB (ATM, see Figure 29) and MORB, i.e., lacking a well-defined negative Nb anomaly but with overall low HFSE and REE abundances, are included in this group because of the high degree of heterogeneity in Nb and Th for a given Y content (see Figure 29). They occur in abundance in the Wild Bight area, but it is known that these rocks are more widespread; however, further definition is hampered by the lack of detailed chemical sampling and analytical data (especially for Th, Nb, REE).

The LOTI group and some of the most depleted IAT-I group were combined to form the 'depleted arc' group. Depleted arc rocks intruded by 'arc-group' and MORB-affinity dykes, constitute most of the eastern outcrop area of the Lushs Bight Group. Fault-bounded blocks of depleted arc volcanic rocks are also found structurally interleaved with boninitic and arc rocks in a linear belt between Little Bay—Davis Brook (cross-hatched area on Figure 38). Present outcrop distribution of the depleted arc rocks is almost certainly controlled by thrust faults (A. Szybinski, personal communication, 1990), with the 'depleted arc' volcanic rocks thrust over the 'arc' rocks.

A summary diagram of the probable stratigraphic, geochemical and isotopic relationships within the Lushs Bight Group is given in Figure 39. Boninitic volcanism appears to have been the first event in the evolution of the Lushs Bight Group. Subsequent volcanism involved less refractory mantle sources and gave rise to the 'depleted arc' (dominantly the LOTI group) and 'arc group' (IAT, ATM, MORB).

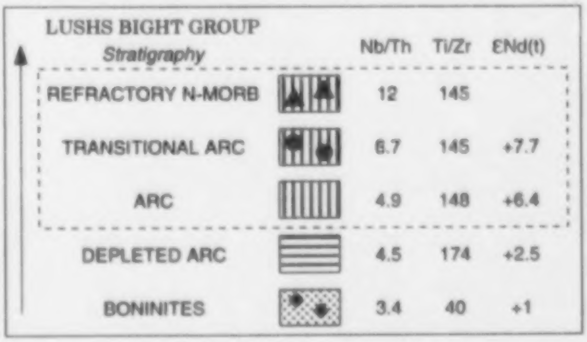


Figure 39. *Summary diagram linking stratigraphic, geochemical and isotopic characteristics of the Lushs Bight Group. Note that symbols and patterns are keyed to Figure 38 (transitional—1542024; ARC—average of 1542249, 1542036, 1542266, 1542267, 1542151, 1542004; depleted ARC—1542116, and boninites—average of 1542118, 1542206, 1543361).*

The stratigraphic relationships of boninites in the Lushs Bight Group differs from those in the Betts Cove Complex (Coish *et al.*, 1982; Coish, 1977). There boninitic pillow lavas are intimately associated with other arc volcanic rocks, and are overlain by non-arc MORB and non-arc transitional tholeiites of the Snooks Arm Group (Jenner and Fryer, 1980; Jenner *et al.*, 1990). Volcanism in the Betts Cove Complex is interpreted to record arc-rifting and back-arc basin formation (Coish *et al.*, 1982; Crawford *et al.*, 1981; Swinden *et al.*, 1989). In contrast, boninites of the Lushs Bight Group are overlain by extensive island-arc tholeiites that are in turn overlain by volcanic rocks of back-arc affinity. There is no record of active boninitic volcanism during the arc to back-arc formation in the Lushs Bight Group. The geochemical evolution of the Lushs Bight Group is shown schematically in Figure 40. The occurrence of boninites in the Lushs Bight Group is consistent with petrogenetic models proposed by Cameron *et al.* (1979), Meijer (1980), and

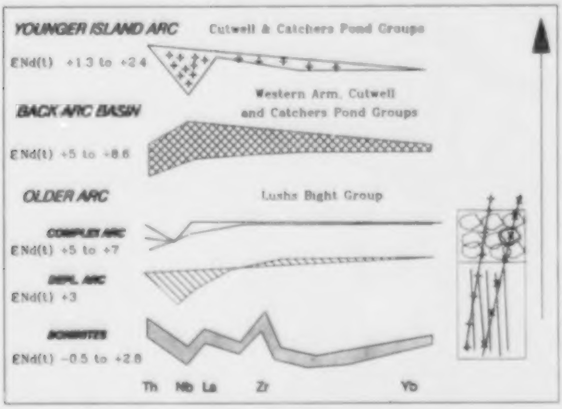

YOUNGER ISLAND ARC
Cutwell & Catchers Pond Groups
ENd(t) +1.3 to +2.4
BACK ARC BASIN
Western Arm, Cutwell and Catchers Pond Groups
ENd(t) +5 to +8.6
OLDER ARC
Lushs Bight Group
COMPLEX ARC
ENd(t) +5 to +7
DEPL. ARC
ENd(t) +3
BONINITES
ENd(t) -0.5 to +2.8
Th
Nb
La
Zr
Yb

Figure 40. *Schematic diagram summarizing tectonic, stratigraphic, geochemical and isotopic features of ophiolitic and volcano-sedimentary groups in western Notre Dame Bay. Arrow on the right side indicates way-up. Inset in lower right corner illustrates ophiolite stratigraphy of the Lushs Bight Group, cut by dykes indicating possible link to the younger island-arc groups (+), and to the back-arc basin groups (x). Note that crosscutting relationships between the CAB and MORB dyke 'types' were not observed.*

Bloomer and Hawkins (1987), which have boninitic volcanism accompanying the earliest stages of island-arc formation.

COLCHESTER AND COOPER'S COVE PLUTONS

The Colchester and Cooper's Cove plutons are composite bodies, ranging in composition from diorite to granite. Major- and trace-element data for representative samples from the plutons are given in Appendix 2, Table 2-4. The geochemical database for these plutons is small, and therefore, any interpretation of tectonic environment is tenuous.

These plutons range in silica content from 54 to 78 percent, but are dominated by rocks having intermediate silica contents (56 to 63 percent). Metaluminous tonalites, minor quartz diorites and granodiorites (Figures 41 and 42) are the most common rock types (LeMaitre, 1989; Kosinowski, 1982; Debon and LeFort, 1983). The plutons are extremely low-K and generally plot in the calc-alkaline field with a minor transgression into the tholeiitic field (Figure 43) (Jensen, 1976; Irving and Baragar, 1971). They are classified as volcanic-arc granites (Figure 44) on the trace-element discrimination plot of Pearce *et al.* (1984a). All of the samples show some degree of light

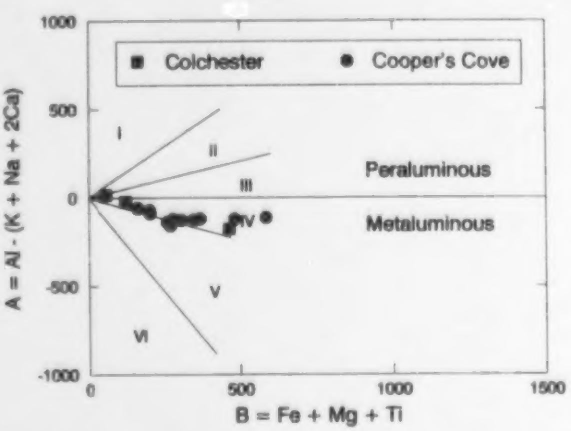


Figure 41. *Metaluminous vs peraluminous plot for the Colchester and Cooper's Cove plutons.*

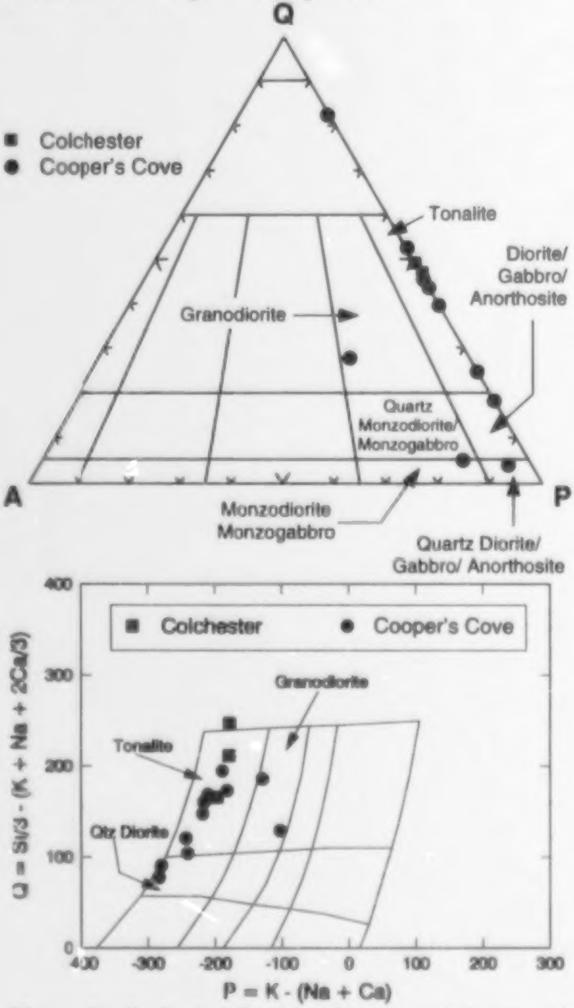


Figure 42. *Rock classification plots for Colchester and Cooper's Cove plutons.*

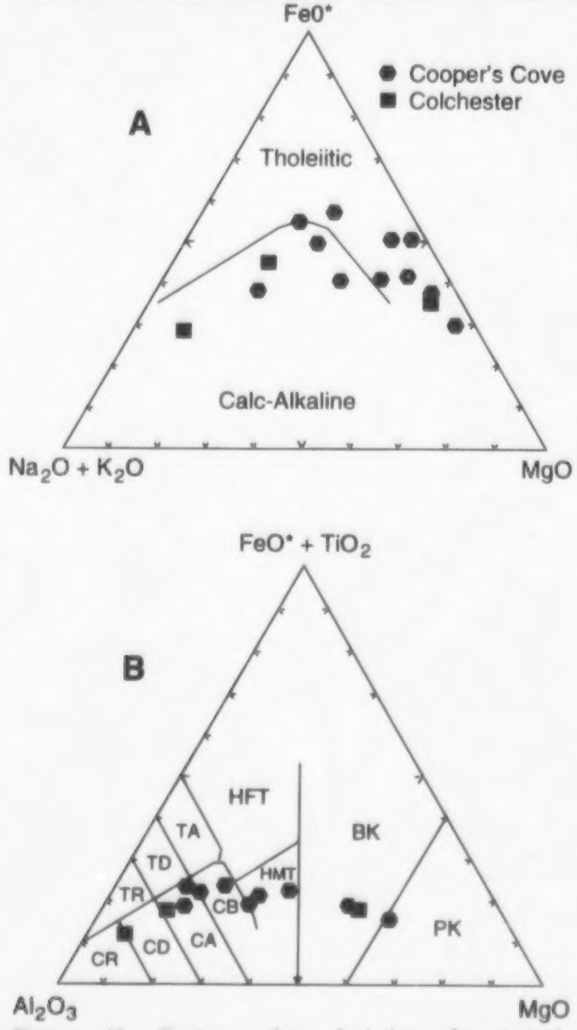


Figure 43. *Ternary plots depicting the tectonic classification of the Colchester and Cooper's Cove plutons.*

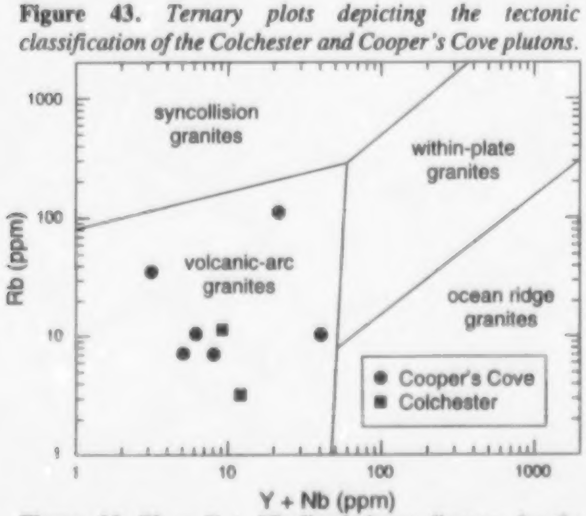


Figure 44. *Rb vs Y + Nb discriminant diagram for the Colchester and Cooper's Cove plutons.*

REE enrichment (Figure 45). The samples having positive Eu-anomalies are probably cumulate in origin. All of the plutonic rocks are characterized by negative Nb-anomalies, consistent with their definition as volcanic-arc granites. The patterns in the plutons show more similarity with the late calc-alkaline dykes than with the felsic dyke (IAT-like) considered part of the Lushs Bight Group.

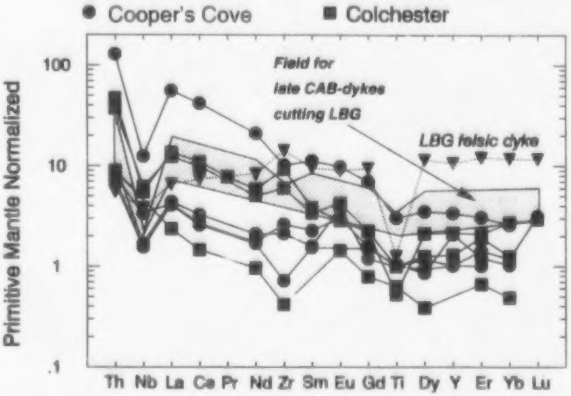


Figure 45. *Primitive mantle normalized plot for plutonic rocks of the Colchester and Cooper's Cove plutons (Samples 1542226, 1542229, 1542271, 1542272, 1542275, 1542311 and 1543324). Comparison field and pattern for later calc-alkalic dykes and a Lushs Bight Group felsite—epidosite dyke overlapped. Normalizing values after Hofmann (1988).*

The origin of the plutonic rocks is not clear. Some of the granodiorites show close compositional affinities with the Toulumme Intrusive Series of the Sierra Nevada Batholith (see Hess, 1989, page 170). However, the low K content suggests more similarity with intra-oceanic arcs. The age of the plutons (~465 Ma, Szybinski, 1995) and the extremely low epsilon Nd in some of these rocks (~ -8 to -10) (G. Jenner, unpublished data, 1992), suggest they are post-collisional granites derived from a K-poor but time-integrated old source. The age of the plutonism makes any obvious correlation with active subduction and with the Lushs Bight Group difficult.

ECONOMIC GEOLOGY

INTRODUCTION

The Lushs Bight Group contains approximately one hundred volcanogenic base-metal sulphide occurrences, showings and prospects, more per square kilometre than any other comparatively sized group of rocks in Newfoundland (Dean, 1978). Figure 46 shows some of the more significant showings and prospects. In addition, there are a number of epigenetic, structurally controlled, vein-hosted showings and prospects, including many recently discovered gold prospects. The gold mineralization is not discussed in detail in this report as its discovery postdates the field studies. The group has been extensively prospected, and has seen the development of three mines—Little Bay, Whalesback and Little Deer. In addition, a number of prospects have been developed.

The volcanogenic mineralization generally occurs in chlorite schist that are derived from the mafic volcanic rocks and is not restricted to any stratigraphic horizon (Figure 47). In many areas, the mineralization is associated with variolitic and quartz amygdaloidal pillow basalt. The varioles have been completely altered to secondary minerals but in places preserve an original radiating texture. Quartz amygdules probably represent silica dumping from the circulating hydrothermal solution that was part of the ore-forming process.

Well-preserved varioles in the Betts Cove ophiolite were interpreted by Saunders (1985) to be primary rather than a secondary devitrification or alteration feature. Saunders (*op. cit.*) further concluded that the varioles represent quench textures (supercooling) developed in rocks of a specific basaltic composition. These basalts are generally more mafic than nonvariolitic varieties and have Cr contents of 400 to 500 ppm and a lower plagioclase content. Pyroxene appears to have crystallized first.

The spatial association of varioles with mineralization may be fortuitous. Ore-forming hydrothermal systems at spreading or rifting sites are extremely localized in areas of anomalously high thermal gradients, i.e., high heat flow (Rona, 1984). These areas are generally restricted to the axial zone of volcanic extrusion immediately over magma bodies (Rona, *op. cit.*). Saunders (1985) postulated that rapid extrusion of hot lava, and hence a greater degree of supercooling and development of quench textures, would probably occur in areas of high heat flow.

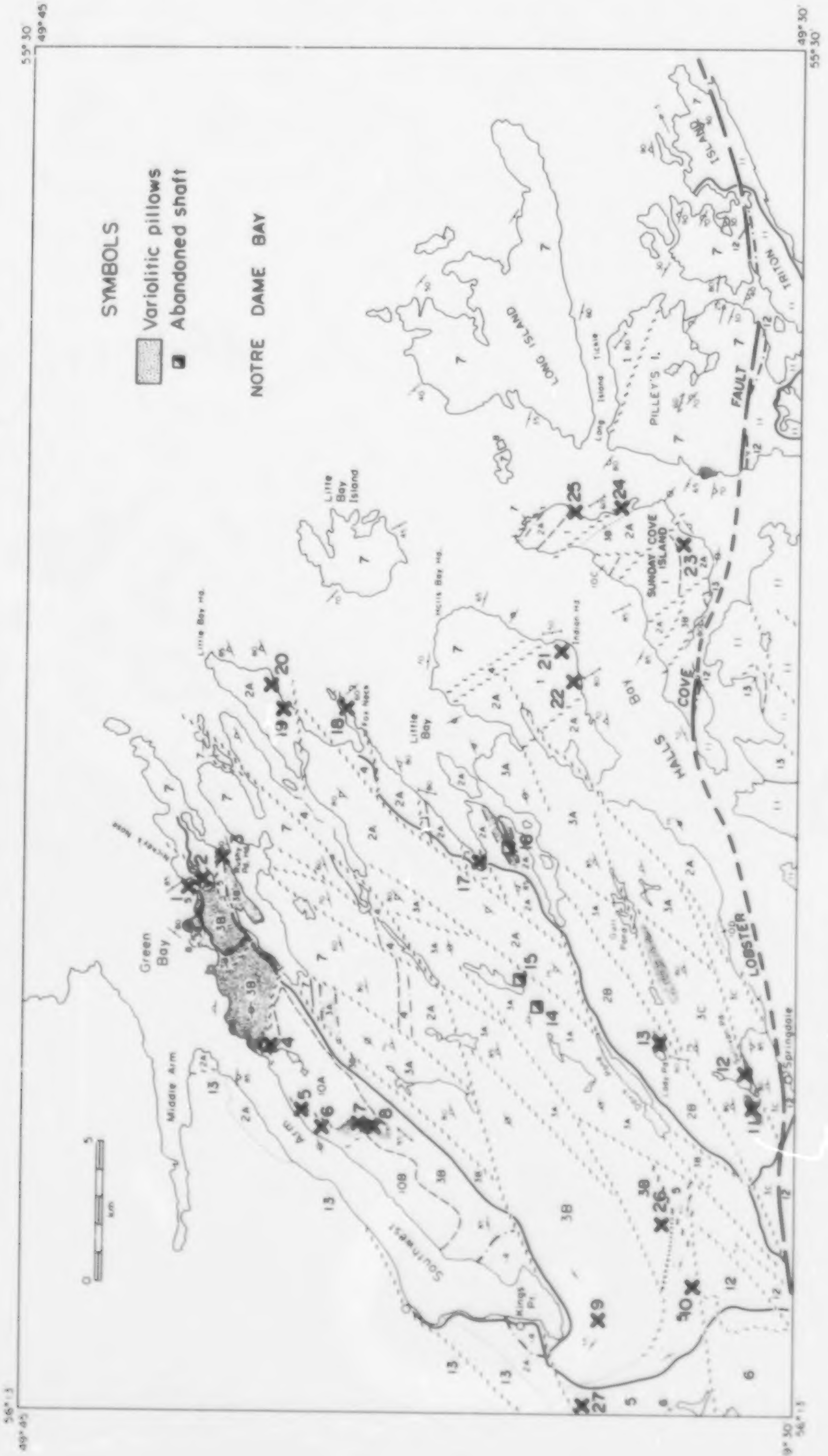
Douglas *et al.* (1940) and MacLean (1947) considered the sulphide deposits to be replacements of chlorite schist in shear zones during the late stages of faulting, and thus to have a common origin. MacLean (*op. cit.*) also suggested a genetic relationship between the sulphides and granodiorite in the area. Williams (1963) concluded that a genetic relationship to volcanism might exist but that the final emplacement and distribution of the sulphides postdated the volcanism and resulted from structural deformation. Kanehira and Bachinski (1968) concluded that the sulphide mineralization, at least in part, predated deformation and metamorphism but also must have postdated the volcanism. West (1972) concluded that the mineralization at the Little Deer mine was post-volcanic.

Kennedy and DeGrace (1972) considered the deposits to predate the main regional deformation because pyrite bands are commonly folded about the associated folds and chalcopyrite is concentrated in fold hinges. Also, in the Whalesback area, the sulphides are cut by predeformation(?) porphyry dykes (Fleming, 1970). Kennedy and DeGrace (1972) observed that, with the exception of the Whalesback and Little Bay mines, the deposits occur in layered tuffaceous rocks. They thus concluded that the mineralization was syn-volcanic.

A syngenetic volcanic origin for the base-metal deposits is thus favoured based on the following evidence: a) they have an early, predeformational origin; b) they are essentially transformed conformable bodies in mafic volcanic rocks, i.e., they are stratabound; c) they possess a simple mineralogy that is similar to volcanogenic deposits hosted by mafic volcanic rocks elsewhere; and d) the chlorite-schist zones are interpreted as early tectonic features that may have acted as loci for upwelling hydrothermal solutions. However, there is no doubt that the deposits have been remobilized and recrystallized during subsequent deformation.

CHLORITE-SCHIST ZONES

A feature common to all the volcanogenic mineralization in the Lushs Bight Group is that it commonly occurs in an envelope of chlorite schist. The chlorite-schist zones are generally developed within pillow lavas and associated rocks, although they are not lithologically controlled. They are broadly concordant with the enclosing rocks, and the sulphide mineralization is in turn broadly concordant within the chlorite-schist zones, although sulphide veins are locally crosscutting. The chlorite-schist zones predominantly consist of black, coarse chlorite with disseminated, euhedral pyrite. In zones of sulphide mineralization the chlorite schist is interlayered


SYMBOLS
Variolitic pillows
Abandoned shaft
NOTRE DAME BAY
Green Bay
Middle Arm
Southwest Arm
Kings Pt.
Little Bay Island
Little Bay
Little Bay Hd.
Fox Neck
LONG ISLAND
Long Island Tickle
PILLEY'S I.
SUNDAY COVE ISLAND
Indian Hd.
HALLS
Bay
COVE
LOBSTER
FAULT
TRITON
ISLAND
Springdale
0
5
km
55°30'
49°45'
56°15'
49°30'

LEGEND

CARBONIFEROUS

14 *Reddish-brown to greyish-red conglomerate and sandstone; grey shale and siltstone and minor limestone*

SILURIAN TO DEVONIAN

13 *Pink to red granite, granodiorite and quartz-feldspar porphyry*

12 SPRINGDALE GROUP: *red and brown conglomerate, sandstone and siltstone; minor volcanic rocks*

EARLY TO MIDDLE ORDOVICIAN

11 ROBERT'S ARM GROUP: *undivided mafic and felsic volcanic rocks*

10 **10A,** Colchester Pluton: *medium-grained diorite, quartz diorite and minor granodiorite.* **10B,** Coopers Cove Pluton: *fine- to coarse-grained diorite, granodiorite and granite, common diabase.* **10C,** Wellmans Cove Pluton: *medium-grained diorite and quartz diorite along with mafic and ultramafic inclusions.* **10D,** Bob Head Pluton: *medium- to coarse-grained diorite, gabbro and quartz monzonite*

9 Brighton Gabbro: *medium- to coarse-grained hornblende clinopyroxene, hornblendite, gabbro, diorite and quartz diorite*

7 WESTERN ARM / CUTWELL GROUPS: *massive along with pillow basalt and andesite, locally feldsparphyric. Lithic and pyroxene crystal -lithic tuff, lapilli tuff, breccia and agglomerate. Epiclastic and sedimentary rocks*

8 *Highly vesicular pillow basalt and feldsparphyric andesite. Lithic and pyroxene crystal - lithic tuff, lapilli tuff and breccia. Interbedded red and green argillite and tuff*

6 CATCHERS POND GROUP: *silicic lava, agglomerate and tuff; massive basalt, pillow lava and agglomerate; thin beds of fossiliferous limestone and limestone conglomerate*

5 *Thinly bedded, grey-green and black, mafic tuff and volcanic sediment; minor red argillite and chert. Magnetite lenses and magnetite-rich tuff locally present; minor basaltic pillow lava*

EARLY ORDOVICIAN AND EARLIER

LUSHS BIGHT GROUP (Units 1 to 4)

4 *Black, locally hematized pillow lava, agglomerate and tuff with common interpillow and lenses of jasper. Overlain by thinly bedded, chocolate-brown argillite and interbedded red chert*

3A *Fine grained to aphanitic, grey to green, epidotized pillow lava with common diabase and gabbro dykes*

3B *Fine grained to aphanitic, grey to green, commonly epidotized pillow lava with extensive pillow breccia and isolated pillows in places. Intercalated mafic tuff, locally extensive*

3C *Fine grained to aphanitic, grey to green, commonly epidotized pillow lava and extensive chlorite schist; highly variolitic and quartz amygdaloidal in places. Mafic agglomerate, breccia and tuff; minor dacitic rocks. Extensive diabase dykes in places and locally sheeted*

2A *Fine grained to aphanitic, grey-green to green, epidotized pillow lava with extensive diabase and gabbro dykes. Minor agglomerate and breccia. Chlorite schist extensive in places*

2B *Undivided sheeted dykes and pillow lava with extensive dykes; locally variolitic. Minor mafic agglomerate, breccia and tuff. Minor dacitic rocks*

1 *Sheeted diabase dykes; locally with gabbro and pillow lava screens*

Figure 46. *Location and listing of sulphide prospects and deposits within the Lushs Bight Group (Table 7 describes those not listed here or discussed in text).*

List of major sulphide and gold occurrences shown in Figure 46.

1. *Nickey's Nose:* Banded pyrite, pyrrhotite and magnetite in black mudstone interbedded with chocolate-brown argillite and minor red chert.

2. *Rushy Pond:* Banded pyrite, pyrrhotite and magnetite in black mudstone interbedded with chocolate-brown argillite and minor red chert.

3. *Rushy Pond Head:* Banded pyrite, pyrrhotite and magnetite in black mudstone interbedded with chocolate-brown argillite and minor red chert.

4. *Swatridge and Swatridge East:* Disseminated and stringer pyrite and chalcopyrite in narrow chlorite-schist zones in pillow lava.

5. *Old English:* Stringer and disseminated pyrite and chalcopyrite associated with minor sphalerite in chlorite schist and quartz veins along the contact with the Colchester Pluton.

6. *South Naked Man:* Pyrite and chalcopyrite in chlorite schist.

7. *Colchester and Southwest Colchester:* Disseminations, stringers and lenses of pyrite, chalcopyrite and pyrrhotite with minor sphalerite in altered pillow lava and breccia.

8. *McNeily:* Disseminations, stringers and bands of pyrite, chalcopyrite and pyrrhotite with minor sphalerite in chlorite schist.

9. *Rendell-Jackman:* Pyrite, chalcopyrite, minor sphalerite and magnetite in chlorite schist derived from tuff.

10. *Yogi Pond and Nolan:* Banded massive pyrite and magnetite in schistose tuff.

11. *Sterling:* Pyrite and chalcopyrite with minor sphalerite as massive lenses, pods, stringers and disseminations in chloritic pillow lava and felsic tuff.

12. *Sullivan Pond:* Disseminated and stringer pyrite and chalcopyrite in chlorite schist.

13. *Lady Pond:* Disseminations, stringers and lenses of pyrite, chalcopyrite and magnetite in pillow lava, altered breccia and schist with extensive diabase dykes.

14. *Little Deer:* Pyrite, chalcopyrite, pyrrhotite and sphalerite as disseminations, stringers, lenses and pods in chlorite schist in pillow lava.

15. *Whalesback:* Pyrite, chalcopyrite, pyrrhotite and sphalerite as disseminations, stringers and banded lenses and pods in chlorite schist in pillow lava.

16. *Little Bay and Sleepy Hollow:* Pyrite, chalcopyrite, pyrrhotite and magnetite as massive lenses and pods, as stringers and disseminations in chlorite schist within pillow lavas and diabase dykes.

17. *Hearn:* Pyrite, chalcopyrite, sphalerite, arsenopyrite, galena and gold in quartz veins and as stringers and disseminations in sheared sheeted dykes with minor pillow screens.

18. *Fox Neck:* Banded pyrite, pyrrhotite and magnetite beds in chocolate brown argillite and red chert.

19. *Shoal Arm:* Pyrite, chalcopyrite, pyrrhotite, sphalerite and arsenopyrite in chlorite schist in pillow lava and diabase dykes.

20. *Little Bay Head:* same as Shoal Arm.

21. *Indian Beach:* Pyrite, chalcopyrite and pyrrhotite in chlorite schist within sheeted diabase dykes.

22. *Indian Head (Keatons Adit):* Pyrite, chalcopyrite and pyrrhotite in chlorite schist within sheeted diabase dykes.

23. *Miles Cove:* Pyrite and chalcopyrite in chlorite schist in pillow lava above sheeted dyke contact.

24. *Jerry Harbour:* Pyrite and chalcopyrite in chlorite schist derived from stuff intercalated with pillow lava.

25. *Paddox Bight:* Pyrite and chalcopyrite disseminations and veins in sheeted dykes with pillow screens.

26. *Timber Pond:* Pyrite, sphalerite and chalcopyrite as stringers and massive lenses in pillow lava and flow breccia.

27. *Hammer Down:* Gold in quartz veins hosted by deformed mafic volcanic rocks.

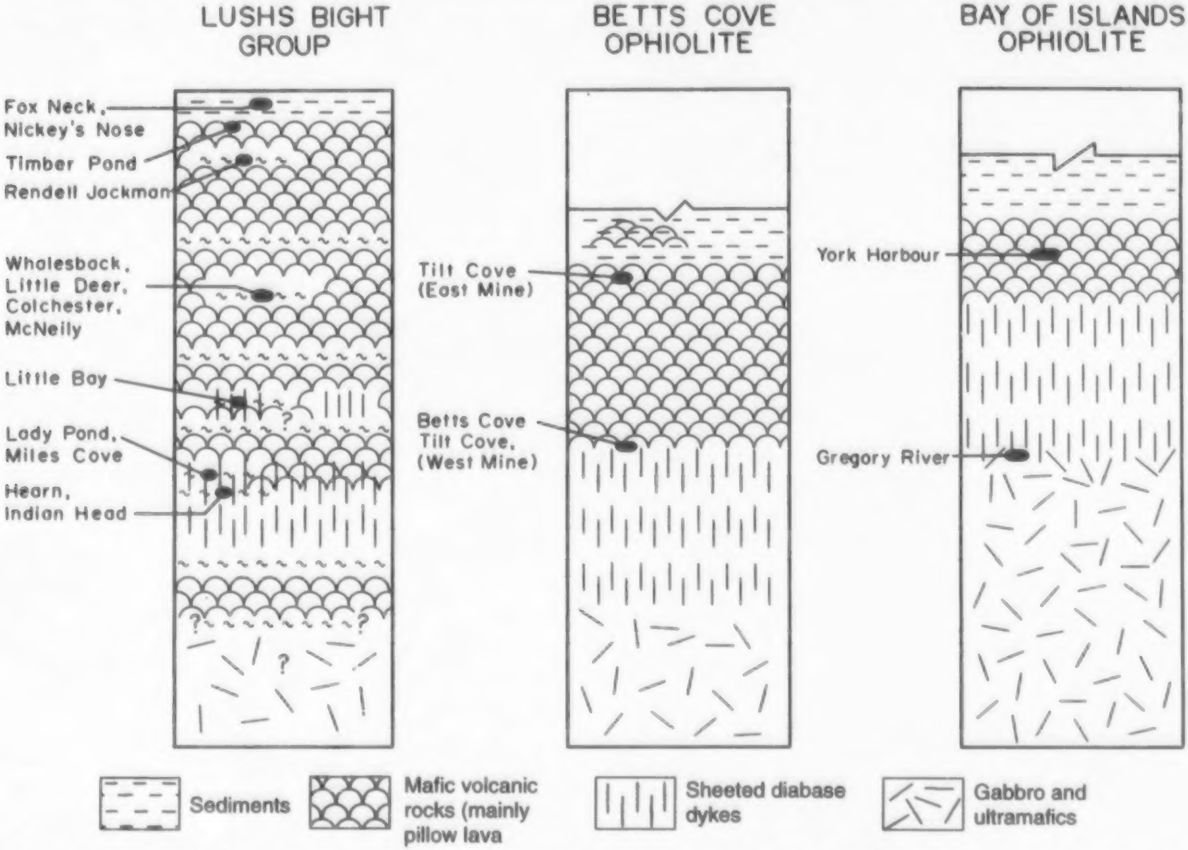

LUSHS BIGHT GROUP
BETTS COVE OPHIOLITE
BAY OF ISLANDS OPHIOLITE
Fox Neck, Nickey's Nose
Timber Pond
Rendell Jockman
Wholesback, Little Deer, Colchester, McNeily
Little Bay
Lady Pond, Miles Cove
Hearn, Indian Head
?
Tilt Cove (East Mine)
Betts Cove Tilt Cove, (West Mine)
York Harbour
Gregory River
Sediments
Mafic volcanic rocks (mainly pillow lava
Sheeted diabase dykes
Gabbro and ultramafics

Figure 47. *Schematic diagram illustrating the stratigraphic settings of mineralization within the Lushs Bight Group, the Betts Cove and Bay of Islands ophiolites.*

with bands of medium-grained, anhedral to euhedral pyrite and strained and recrystallized quartz containing disseminated euhedral pyrite. The quartz bands are interpreted to be transposed quartz veins and veinlets. Sericite is generally a minor constituent. However, in the Little Deer chlorite-schist zone, sericite is present in amounts up to 25 percent.

The chlorite-schist shear zones are interpreted to be early structures (see Kennedy and DeGrace, 1972) resulting from the superimposition of a regional penetrative foliation on an earlier, locally (or at least inhomogeneously) developed fabric. The early phase of deformation may be related to fracture/fault zones which originated in the early stages of volcanic activity. These fracture/fault zones are interpreted to represent zones of weakness along which subsequent upward migration of hydrothermal fluids occurred. The fluids would have altered the country rock through which they passed. Subsequent deformation resulted in the development of chlorite-schist shear zones.

Spooner and Fyfe (1973) regarded sub-seafloor discharge sites as being controlled by fractures and faults. Adamides (1980) proposed a fault control model for the siting of ophiolitic deposits at Kalavasos, Cyprus. Saunders (1985) and Saunders and Strong (1986) proposed a similar model for the Betts Cove deposit, Newfoundland (Figure 48). Rona (1984) also noted the fault/fracture control on the siting of ore-forming hydrothermal systems at seafloor spreading centres.

Sundblad (1980) discussed the effects of pure shear, simple shear and combinations thereof on the classic volcanogenic massive sulphide model. Sundblad (*op. cit.*) concluded that shearing of volcanogenic massive sulphides results in development of a subparallelism of originally vertical and horizontal components (Figure 49). In the Lushs Bight Group, the fault—fracture-controlled chlorite-rich alteration zones probably behaved as incompetent zones along which subsequent deformation is more intensely developed. The alteration zones and associated mineralization were subsequently transposed into lensoidal zones subparallel to the regional trend.

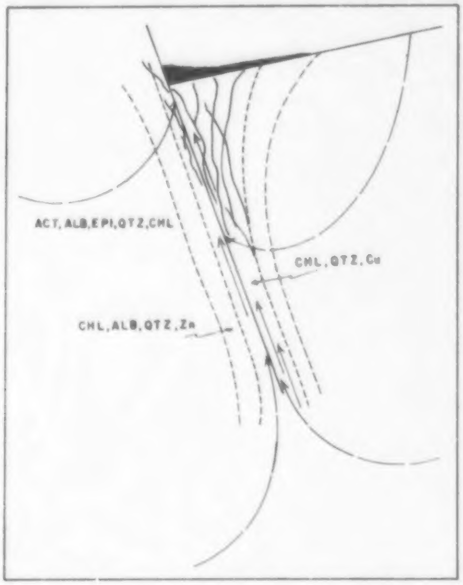


Figure 48. *Fault-controlled discharge site and mineralization in an hydrothermal system. Mineralizing fluids move up along the zones of weakness producing stockwork alteration and exhalative massive sulphides (shaded area) (from Saunders, 1985; modified after Adamides, 1980). ACT—actinolite, ALB—albite, CHL—chlorite, Cu—copper, EPI—epidote, QTZ—quartz, Zn—zinc.*

In addition to having been a locus for deformation, the chlorite-schist zones are characterized by a mineralogical and chemical change (redistribution of elements). There is a gradational disappearance of calcite, epidote and plagioclase (albite) progressing from the host metabasalts into the chlorite schist. The end product consists almost entirely of black chlorite, sulphide and quartz. Silicification and minor sericitization and rare carbonitization are locally developed in the sulphide zones. This mineralogical change is reflected in the chemistry. Papezik and Fleming (1967) noted that the chlorite-schist zones were enriched in iron and water and depleted in calcium and silica relative to the host basalts. Bachinski (1973, 1977) demonstrated the almost complete leaching of sodium and calcium (Figure 50) and the addition of iron and sulphur to the chloritic schist hosting the Whalesback deposit. Potassium showed erratic enrichment and there were no significant changes in SiO_2, Al_2O_3, TiO_2, MgO and MnO. He concluded that this alteration predated regional greenschist metamorphism and was probably associated with hydrothermal activity related to ore formation.

Gale (1969) demonstrated a similar decrease in sodium across chlorite-schist zones hosting the Lady Pond, Little Deer and Little Bay deposits. The chlorite-schist zones are further characterized by an increase in Cu, Zn and Mn content (Figures 51 and 52). He concluded that the Na was removed from the rock and carried away by epigenetic hydrothermal, pre-ore and/or ore-forming fluids. The Zn and Cu were also interpreted to be introduced by epigenetic hydrothermal fluids.

Similar chemical changes have been documented in volcanogenic sulphide occurrences elsewhere in Newfoundland. Saunders (1985) showed that the chlorite-dominated alteration zone at Betts Cove is characterized by anomalously high total iron, Cu and Zn and extreme depletion of CaO and Na_2O and concluded that these chemical characteristics were imparted by a hydrothermal mineralizing system. Duke and Hutchinson (1974) described chloritic rocks with CaO depletion and slight SiO_2 enrichment associated with the York Harbour deposit in the Bay of Islands ophiolite.

The chlorite in the mineralized chlorite schists display distinctive optical and chemical properties. The chlorites are, with minor exceptions, dark-green, pleochroic with a strong anomalous blue interference colour, and generally within the brunsvigite—ripidolite composition range (Figure 3). Chlorite from the greenschist, host basalts and schist outside of the mineralization are generally brownish, greenish or purplish and consistently fall within the pycnochlorite—ripidiolite field. Chlorite compositions show a progression from magnesium-rich chlorites in the unmineralized metabasalts and schist (coexisting with actinolite and epidote) into iron-rich chlorites from the mineralized schists (Figure 7). The most iron-rich chlorites are from the ore zones and coexist with pyrite and quartz. This conforms with the chlorite compositions in chlorite—quartz-sulphide-rich breccias in an upwelling hydrothermal system (Mottl, 1983).

Structural and geochemical evidence and comparisons with other areas suggest that the chlorite-schist zones associated with mineralization represent hydrothermal alteration pipes that were probably developed along sites of weakness, such as faults, fractures, contacts and breccia zones. Subsequent deformation, probably a combination of simple and pure shear, has resulted in a subparallelism of original vertical and horizontal elements.

MINERAL DEPOSITS

The mineral deposits in the area are discussed under four main groupings: (1) mineral occurrences hosted by sheeted diabase dykes, (2) mineral occurrences associated with mafic volcanic rocks, (3) mineral occurrences in sedimentary rocks overlying the mafic volcanic rocks, and

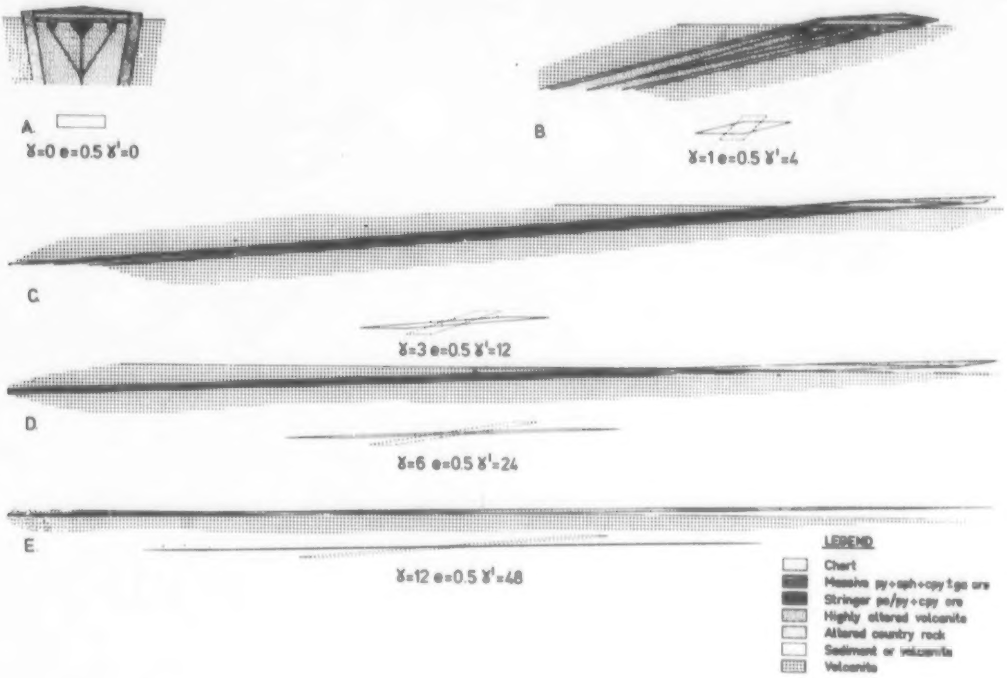


Figure 49. *Deformation of a generalized volcanogenic massive sulphide deposit by a combination of simple shear and later pure simple shear (Sundblad, 1980). (γ values = 0, 1, 3, 6 and 12 respectively parallel to the original layering and later pure shear (e = 0.5) applied perpendicular to the original layering; γ' are effectively angular distortions when compared to the original model A.*

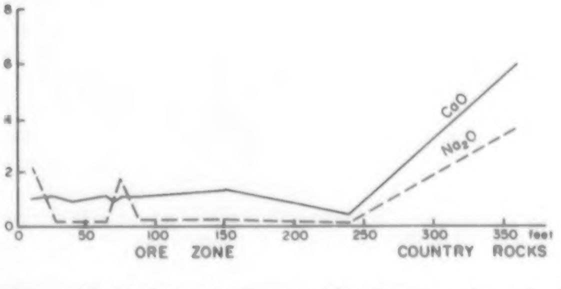


Figure 50. *Variation in CaO and Na_2O across the end of the Whalesback ore zone (Bachinski, 1977). Section taken along the Whalesback Pond drainage tunnel with the portal being at 0.*

(4) structurally controlled, mesothermal quartz vein systems.

The major prospects and showings characteristic of the different deposit types are discussed in detail. Minor prospects, showings and indications for which there is little geological information are listed in Table 7. The NTS number followed by a commodity symbol and number is a reference to the Department of Natural Resources Mineral Occurrence Data System. Table 8 gives assay results for some of the mineral showings within the Lushs Bight Group. Measurements and tonnages have been converted to metric in the text; however, information on reproduced or copied figures, tables and diagrams have not been converted. Figure 47 schematically illustrates the stratigraphic position of major deposits in the Lushs Bight Group.

Mineral Occurrences Hosted by Sheeted Diabase Dykes

Sporadic pyrite and minor chalcopyrite occur throughout the sheeted diabase dykes and locally in the associated gabbros. Sulphides are particularly abundant in areas where there is significant mineralization in the associated pillow lava and in areas where pillow screens are found in the sheeted-dyke horizon. The areas of significant mineralization are generally characterized by chloritization and development of chlorite schist. The mineralization occurs as sulphide disseminations, veins and stringers, and quartz and carbonate veins carrying pyrite, chalcopyrite, sphalerite, minor galena and locally gold (e.g., Hearn gold prospect near Little Bay). Prospects in

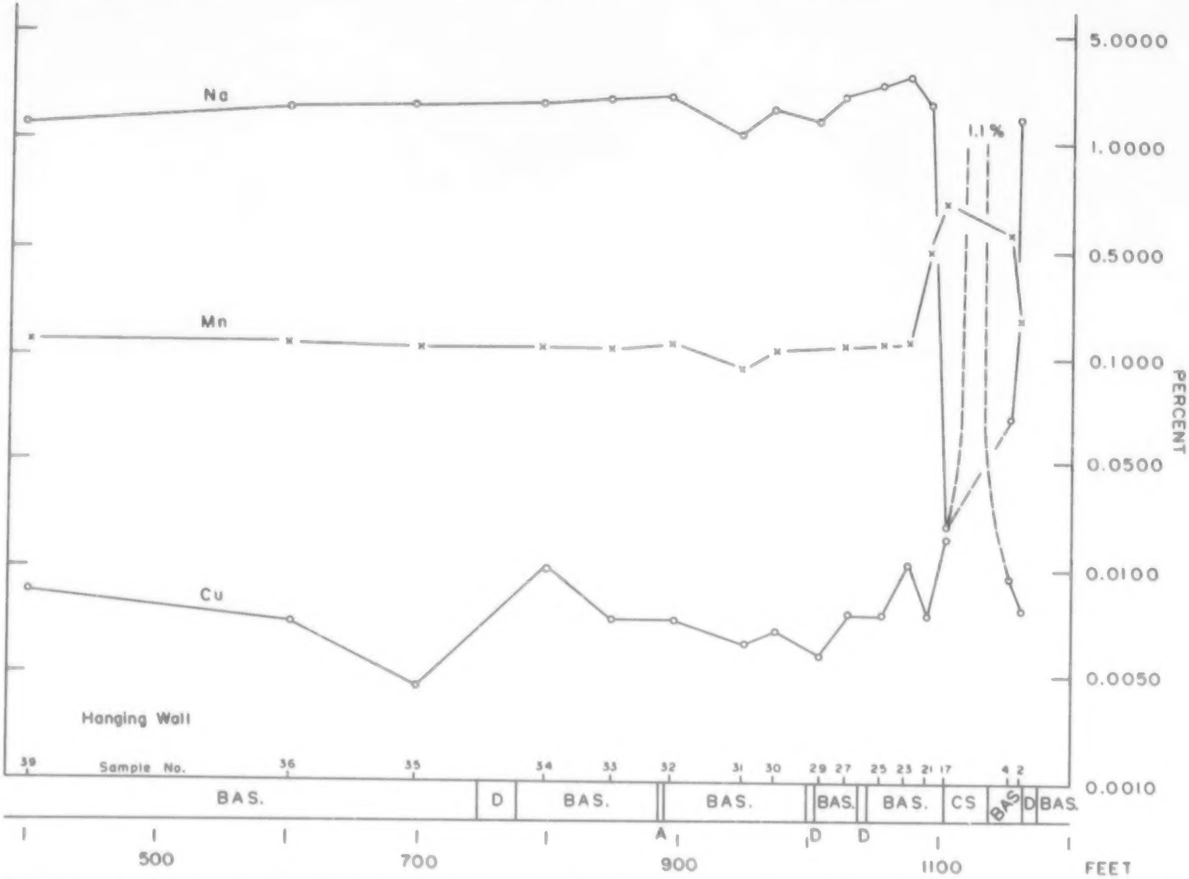


Figure 51. *Variations in Na, Mn, and Cu in drill hole #132, Little Deer Mine (after Gale, 1969) (A—amphibole—feldspar porphyry; D—diorite; BAS—basaltic volcanic rocks; CS—chlorite schist).*

sheeted dykes include the Indian Beach, Indian Head (Keatons Adit), Wellman's Cove Adit and Paddock's Pond Brook.

Indian Head (Keatons Adit) (NTS 2E/12 Cu026)

Location

The showing is located at Indian Head on the north side of Halls Bay. The area is accessible by boat.

History of Development

There is no record of the early development. However, Douglas *et al.* (1940) reported the adit to be about 30 m long. There has been no further development of the showing, although it has been investigated by a number of exploration companies.

Local Geology and Mineralization

The showing occurs in sheared, sheeted diabase dykes. It consists of disseminated pyrite and minor chalcopyrite in a narrow, chloritized and weakly silicified shear zone developed in sheeted diabase dykes. Malachite staining is present in the cliffs along the coast.

Douglas *et al.* (1940) described the showing as follows:

> "The sheared greenstones, striking S 40°E and dipping vertical to very steeply northeast, are weakly pyritized, chloritized, and silicified over a width of several feet. Only traces of chalcopyrite were found. The adit has been driven N 60°E for about 100 feet, but not along enough to cut the pyritized zone which outcrops on the hillside above the adit. The prospect has no value."

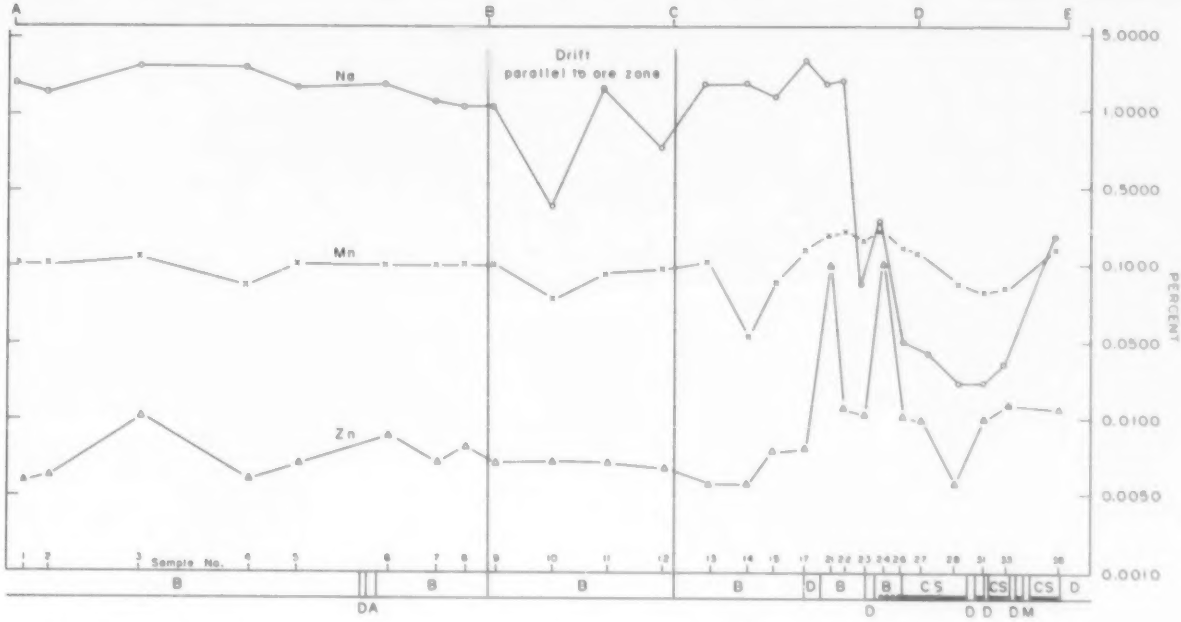


Figure 52. *Variations in Na, Mn and Zn content in 1350 level, Little Bay Mine (Gale, 1969). M—mafic dyke; D—diorite dyke; B—volcanic rocks; CS—chlorite schist;* ▬ *> 1 percent Cu;* ••• *< 1 percent Cu.*

MacLean (1947) also examined the showing as part of his investigation of the geology and mineral deposits of the Little Bay area.

Indian Beach (NTS 2E/12 Cu027)

Location

The prospect is located on the north side of Halls Bay, approximately 600 m inland from Indian Beach. The prospect is accessible by boat.

History of Development

The prospect was developed by Enos England, who traced the sheared zone for over 124 m along the eastern slope of a small valley. Development work included 21 to 24 m of stripping where pyrite, chalcopyrite, and sparse pyrrhotite occur in a chloritized section of the shear. A shaft was sunk to a depth of approximately 6 m near the southern end of the shear and one or two tonnes of hand-sorted ore were piled near the shaft. The prospect was examined by Douglas *et al.* (1940) and MacLean (1947).

Local Geology and Mineralization

The prospect occurs in chlorite shear zones developed within sheeted diabase dykes. The shearing subparallels the trend of the dykes, i.e., northwest—southeast, and dips 70° west.

Douglas *et al.* (1940) described the mineralization as follows:

> "The shearing and mineralization are spread in narrow bands over a width of from 5 to 10 feet, giving an actual sulphide mineralization of only 1 or 2 feet. ... the vein has about 2 feet of pyritic mineralization at the footwall and the hanging wall, with 5 or 6 feet of barren rock between.
>
> ..... A sample chipped from about twenty pieces of this ore assayed: copper 3.86%; sulphur 6.50%; gold trace; silver 0.07 oz. per short ton."

Mineralization in Mafic Volcanic Rocks

The majority of sulphide occurrences within the Lushs Bight Group occur in chlorite schists developed within pillow lava and/or intercalated pyroclastic rocks. The pillow lavas are generally variolitic and quartz amygdaloidal. The mineralization occurs at different stratigraphic positions within the pillow sequence (Figure 47) and has no obvious close spatial relationship to the sheeted dykes. A small number of occurrences appear to be located near the pillow lava—sheeted dyke contacts where abundant diabase dykes cut the pillow lavas (e.g., Miles Cove, North Paddocks Bight). The exact

Table 7. Listing of mineral showings, prospects and indications in the Lushs Bight Group not discussed in the text

Name	Status[1]	NTS/MODS	Style of Mineralization	Host Rock	Mineralogy and Grades[2]	Comments	References
				Mineralization hosted by sheeted dykes			
Old Mines	I	12H/9 Cu034	Disseminated and massive	Chlorite schist within sheeted dykes	cp, pyr	Several trenches ca. late 1800s.	Dean, 1977
Pilley's Cove	I	2E/12 Cu010	Disseminated	Chlorite schist within sheeted dykes	pyr, cp		Dean, 1977
Wellman's Cove	I	2E/12 Cu019	Stringers and quartz veins	Chlorite schist within sheeted dykes	pyr, cp		Dean, 1977
N. Port Anson E.	I	2E/12 Pyr006	Disseminated (?)	Chlorite schist within diabase dykes	pyr		Dean, 1977
Wellman's Cove Shaft	I	2E/12 Pyr007	Dissemianted (?)	Chlorite schist within diabase dykes	pyr		Dean, 1977
Shoal Point	I	2E/12 Pyr008	Stringers and bands	Chlorite schist within diabase dykes	pyr		Dean, 1977
				Mineralization in volcanic rocks			
Rambler Pond	S	12H/9 Au008	Jasper-iron formation	Chlorite schist	Au 2.44 g/t Au (gs)	Discovered by Noranda in 1989.	Terra Gold Resources Inc. Preliminary Prospectus, 1989
Anvil Pond	P	12H/9 Cu012	Veinlets, blebs and aggregates	Chlorite schist within pillow lava	cp, pyr 2.82% Cu (gs)	Several early exploration trenches. Detailed work by BRINEX from 1965-1969. 11 diamond drill holes drilled in 1967 and 5 in 1969.	Morris, 1966 BRINEX, 1967a Peters, 1969
Vein Pond	P	12H/9 Cu014	Disseminated sulphides	Chlorite schist within pillow lava	cp, pyr 0.84% Cu, 0.020% Zn, 0.19 oz/ton Ag, 0.026 oz/ton Au over 5 ft.	Discovered by BRINEX in 1963; conducted detailed mapping and geophysics. 3 diamond drill-holes drilled in 1964 and 2 in 1969.	Smajovic, 1963 Bedford, 1964 James, 1969
Big Deer Pond	P	12H/9 Cu015	Disseminations and stringers	Chlorite schist within pillow lava	cp, pyr 2.82% Cu over 10 ft.	Discovered by BRINEX in 1962. The company carried out detailed exploration work in 1962 and diamond drilling in 1963.	Roderick, 1962 Bedford *et al.*, 1963
Mine Pond Shaft	P	12H/9 Cu016	Massive and disseminated	Chlorite schist within pillow lava	cp, pyr 2.28% Cu over 10 ft.	A 6 m shaft and several trenches ca. late 1800s. Explored by BRINEX in 1962-63 under the Big Deer-Mine Pond project.	MacLean, 1947 Roderick, 1962 Bedford *et al.*, 1963
Hill Prospect	P	12H/9 Cu017	Fracture fillings and disseminations	Chlorite schist within pillow lava	cp, pyr 2% Cu (gs)	Discovered by BRINEX in 1963; trenches and geophysical and geochemical surveys.	Bedford *et al.*, 1963
Duck Pond	S	12H/9 Cu018	Disseminations and stringers	Chlorite schist within pillow lava	cp, sp, pyr 0.06% Cu and 1.07% Zn over 3.5m and 0.06% Cu over 1.6 m.	Discovered by BRINEX in 1962 and trenched and sampled in 1962-63. 1 diamond drill-hole drilled in 1962 and 4 in 1966.	Bedford *et al.*, 1963 BRINEX, 1966
Little Bay Pond (Road Shear)	S	12H/9 Cu019	Disseminations and quartz veinlets	Chlorite schist within pillow lava	cp, po, sp, pyr 0.2% Cu and 0.24% Zn over 1.6m and 0.04% Cu and 1.60% Zn over 0.4 m.	Discovered by BRINEX in 1955. 1 diamond drill-hole drilled in 1966. 2 diamond drill-holes drilled in 1967.	Peters, 1955 BRINEX, 1966

Table 7. Continued

Name	Status[1]	NTS/MODS	Style of Mineralization	Host Rock	Mineralogy and Grades[2]	Comments	References
Delgado	S	12H/9 Cu020	Disseminations and veinlets	Chlorite schist within pillow lava	cp, po, pyr	Discovered at the turn of the century. BRINEX conducted geological mapping of the area in 1962.	Newham, 1962
Davis Creek	S	12H/9 Cu021	Disseminations and veinlets	Chlorite schist within pillow lava	cp, pyr	Discovered and trenched in the early 1900s. The area was mapped by BRINEX in 1962.	Newham, 1962
Buckshee Brook	S	12H/9 Cu022	Disseminations and fine veinlets	Chlorite schist within pillow lava	cp, pyr Best assay 1.48 % Cu >over 2.0 ft.	Discovered by BRINEX in 1965. The company conducted detailed geophysical, geochemical surveys and mapping from 1965-66. BSc. thesis by James, 1967. Four diamond drill-holes drilled in 1969.	Bedford, 1966 James, 1967 Murthy, 1969
Davis Pond NE	P	12H/9 Cu025	Disseminated sulphides	Chlorite schist within pillow lava	pyr, cp, Sp, Au 0.035% Cu, 0.38% Zn, 0.002 oz/t Au (dc) 0.015% Cu, 0.55% Zn, 0.002 oz/t Au (dc)	L.M.&E. conducted a joint venture helicopter-borne EM and magnetometer survey with BRINEX in 1975. Detailed work in 1976 by L.M.&E. lead to the drilling of 2 holes in 1977 and 1 hole in 1980.	Ford, 1977 Tuffy, 1977 Avison, 1981
Lady Pond NE	S	12H/9 Cu026	Disseminated (?)	Chlorite schist within pillow lava	cp, po, pyr 0.06% Cu and 0.03% Zn (gs)	A single shaft was sunk during the 1890s. BRINEX conducted a helicopter-borne EM and magnetic survey in 1976. L.M.&E. followed-up the anomalies under a joint venture with BRINEX in 1977.	Ford, 1977
Browns Pond Shafts	S	12H/9 Cu027	Disseminated	Chlorite schist within pillow lava	cp, pyr	Shallow shafts and pits ca. 1890s. BRINEX drilled 3 diamond drill-holes in 1964.	MacLean, 1947 BRINEX, 1964
Ferndale	I	12H/9 Cu028	Disseminated	Chlorite schist within pillow lava	cp	Probably discovered in the late 1890s.	Sayeed, 1970
South Naked Man	I	12H/9 Cu030	Disseminated	Chlorite schist within diorite	cp, pyr	Trenches ca. 1870s. The area was examined by M.J. Boylon Eng. Co. and Cerro Mining Corp. in 1969.	Sayeed, 1970
St. Patricks	I	12H/9 Cu032	Disseminated	Chlorite schist within pillow lava	cp, pyr		Dean, 1977
Goodyears Pond	I	12H/9 Cu033	Disseminated and massive	Chlorite schist within pillow lava	cp, pyr	Discovered and trenched in the late 1800s. Mapped by BRINEX in 1964-65.	Bedford, 1966
Shilly Cove	I	12H/9 Mag001	Massive	Red chert and pillow lava	mag	Discovered during this study.	
Nolan	S	12H/9 Pyr002	Massive banded sulphides	Chlorite schist within pillow lava	mag, pyr	Named for BRINEX geologist F.J. Nolan in 1962. Explored by BRINEX in 1962. 1 trench was dug across the zone in 1970.	DeGrace, 1971
Sullivan Pond East	S	12H/9 Pyr003	Disseminations, lenses and stringers	Chlorite schist within pillow lava	cp, pyr	Discovered and trenched in the late 1800s. First examined by BRINEX in 1955. BRINEX conducted detailed exploration of the area in 1965. 11 holes were drilled in 1967 and 5 in 1969.	Morris, 1966 BRINEX, 1967 Peters, 1969
King's Point Road	I	12H/9 Pyr010	Disseminated and massive	Chlorite schist within pillow lava	cp, pyr	Discovered during this study. Occurs as interpillow disseminations and massive lens.	

Table 7. Continued

Name	Status[1]	NTS/MODS	Style of Mineralization	Host Rock	Mineralogy and Grades[2]	Comments	References
South Shilly Pond	I	12H/9 Pyr011	Disseminated	Chlorite tuffaceous rocks	pyr, minor cp	Mapped and sampled by BRINEX in 1981.	Tuach, 1982
Mine Pond	I	12H/9 Pyr012	Quartz vein and disseminations	Chlorite schist	cp, pyr	Exploration shaft of unknown origin. Mapped and sampled by BRINEX 1981.	Tuach, 1982
Shimmy Pond	S	2E/12 Au003		Sheared, silicified tuffs and agglomerate	Au 7.44 g/t over 1.8 m (cs)		Burton, 1984
Sunday Cove Island W	I	2E/12 Cu011	Disseminated (?)	Chlorite schist within pillow lava	pyr, cp, chal		Dean, 1977
Wellmans Cove S	I	2E/12 Cu013	Stringers and quartz veins	Chlorite schist within pillow lava	pyr, cp		Dean, 1977
Wellmans Cove Adit	S	2E/12 Cu014	Disseminated	Chlorite schist within pillow lava	pyr, cp 7.1% Cu, 0.17% Zn, 0.1 ppm Au (cs)	A 5 m shaft ca. late 1800s.	Bradley and Lilly, 1964 Howse and Collins, 1979
Bobs Head	I	2E/12 Cu025	Quartz-calcite veins	Chlorite schist within pillow lava	pyr, cp	Early exploration attempts consisted of a couple of small pits sunk about 1916.	MacLean, 1947
St. Patricks SW	I	2E/12 Cu028	Disseminated (?)	Chlorite schist within pillow lava	pyr, cp		Dean, 1977
Woodfords Cove	I	2E/12 Cu034	Disseminated (?)	Chlorite schist within pillow lava	pyr, cp		MacLean, 1947
Rowsell Cove	I	2E/12 Pyr009	Massive banded sulphides	Red chert within pillow lava	pyr, hem		Dean, 1977
Osmond Cove	S	2E/12 Pyr012	Massive sulphides	Chlorite schist within pillow lava	pyr	The Little Bay Mining Co. explored the area ca. 1908 and dug 2 pits 25 m apart. BRINEX examined the area as part of their regional exploration program.	MacLean, 1947
Shoal Harbour West	S	2E/12 Pyr027	Disseminated	Chlorite schist within pillow lava	pyr, cp	Small shaft dating from the late 1800s. Rediscovered during this study.	
Shoal Harbour	S	2E/12 Pyr028	Disseminated	Chlorite schist within pillow lava	pyr, cp	Small shaft dating from the late 1800s. Rediscovered during this study.	
Bartletts Cove		2E/12 Pyr029	Veins, disseminations and massive zones	Chlorite schist within pillow lava	pyr, gn, sp	Discovered during this study.	Kean, 1983
Knife Cove	I	2E/12 Pyr032	Disseminated	Chlorite schist	pyr, cp	Rediscovered by Inco 1989. Not previously reported although evidence of old activity.	R. Bell, pers. comm., 1989
Parr Shaft	I	2E/12 Pyr033	Disseminated and stringer	Chlorite schist	pyr, cp		M. Collins, pers. comm., 1990
				Mineralization in sediments overlying the top of the Lushs Bight Group			
Yogi Pond North	I	12H/9 Pyr014	Massive bedded sulphides	Argillaceous sediments	pyr, mag, po	Discovered during this study.	
Shag Cliff	I	2E/12 Pyr031	Disseminated	Black argillitaceous sediments	pyr	Discovered during this study.	

Table 7. Continued

Name	Status[1]	NTS/MODS	Style of Mineralization	Host Rock	Mineralogy and Grades[2]	Comments	References
					Vein-hosted mineralization		
Lard Pond	S	12H/9 Au002	Sulphide-bearing quartz veins	Epidotized pillow lava	Au, Ag, asp, gn, cp, pyr	Two early exploration trenches. Detailed mapping by BRINEX in 1963.	Bedford *et al.*, 1963
Burnt Berry	S	12H/9 Au004	Unknown	Chlorite schist	Au 5.7 g/t over 7 m.	Discovered by Noranda in 1988.	Terra Gold Resources Inc. Preliminary Prospectus, 1989.
Pine Pond 1 (Maple Leaf Brook North)	S	12H/9 Au005	Quartz veins with massive sulphides	Chlorite schist	Au 55.4 g/t Au and 35.5 g/t Au (gs)	Discovered by Noranda in 1988	Terra Gold Resources Inc. Preliminary Prospectus, 1989.
Pine Pond 2 (Maple Leaf Brook South)	S	12H/9 Au006	Quartz vein	Chlorite schist	Au, cp, pyr, mal 4.51 g/t Au and 6-8% Cu (gs)	Discovered by Noranda in 1988.	Terra Gold Resources Inc. Preliminary Prospectus, 1989.
Pine Pond 3	S	12H/9 Au007	Quartz vein	Chlorite schist	Au 2.53 g/t Au (gs)	Discovered by Noranda in 1988	Terra Gold Resources Inc. Preliminary Prospectus, 1989.
Northwest Brook	I	12H/9 Cu029	Quartz veins	Chlorite schist within the marginal phase of the Colchester Pluton	cp,pyr	Discovered by BRINEX in 1969.	Sayeed, 1970
Wells Prospect	S	12H/9 Cu031	Quartz vein	Pillow lava, diabase and gabbroic dykes	cp, sp, po, pyr, mar 0.04 oz/ton Au, and 0.01 oz/ton Au, 10.3% Cu (cs)	Discovered and trenched prior to 1938.	Douglas *et al.*, 1940 MacLean, 1947 Sayeed, 1970
Paddocks Pond Brook	I	2E/12 Cu042	Disseminations and quartz veins	Chlorite schist within pillow lava	cp, sp, Au, pyr 4.3% Cu, 2.0% Zn, 41 ppm Pb, 1.5 ppm Au (float)	Department of Mines personnel conducted detailed mapping, soil sampling, ground magnetic, VLF-EM and CEM surveys in 1978.	Bradley and Lilly, 1964 Howse and Collins, 1979
Three Corner Pond	I	12H/9 Mo001	Quartz veins and fractures	Granodiorite and pillow lava	pyr, cp, mag, mo	Detailed work conducted by BRINEX in 1981.	McHale, 1981
Three Corner Pond	I	12H/9 Mo002	Quartz veins and fractures	Granodiorite and pillow lava	pyr, cp, mag, mo	Detailed work conducted by BRINEX in 1981.	McHale, 1981
Brighton Island	I	2E/12 Mo001	Disseminations and patches	Aplite veins	pyr, cp, mo	Discovered during this study.	

1. I-Indication; S-Showing; P-Prospect.
2. (gs)-grab sample; (cs)-chip sample; (dc)-drill core.

Abbreviations:
cp-chalcopyrite, pyr-pyrite, sp-sphalerite, po-pyrrhotite, mag-magnetite, chal-chalcocite, hem-hematite, gn-galena, asp-arsenopyrite, mal-malachite, mar-marcasite, mo-molybdenite, Au-gold, Cu-copper, Zn-zinc, Ag-silver

Table 8. Assay results of grab samples collected from old mine dumps and workings

SHOWING	% Cu	% Zn	% Pb	ppb Au	ppm Ag
Miles Cove	5.22	0.07	<.01	1335	4
Miles Cove	3.28	0.18	<.01	815	3
Little Bay	10.42	0.32	<.01	6480	3
Little Bay	13.05	0.04	<.01	2660	6
Little Deer	4.49	0.07	<.01	258	6
Little Deer	21.94	0.09	<.01	440	16
Lady Pond	3.32	0.01	<.01	135	2
Lady Pond NE	8.88	0.16	<.01	70	20
Sterling	4.80	<0.01	0.02	95	6
McNeily	0.26	0.88	0.03	4020	10
Colchester	0.82	0.02	<.01	420	0.7
Colchester	3.65	0.06	<.01	716	1
Rendell-Jackman	4.61	0.10	0.02	5400	10
Rendell-Jackman	3.04	0.12	<.01	2150	9
Delaney	8.1	0.14	<.01	775	24.4
Fox Neck	0.05	<0.01	<.01	34	0.7
Nickey's Nose	0.02	0.01	<0.01	90	0.1
Nickey's Nose	0.03	<0.01	<0.01	220	0.4
Rushy Pond	<0.01	<0.01	0.02	75	0.2
Silverdale	1.70	0.19	18.23	560	1414
Jerrys Harbour	2.52	0.26	—	850	n.d.

(n.d. not determined)

stratigraphic positions of most occurrences are not established (e.g., Rendell-Jackman, Little Deer, Whalesback, McNeilly and Colchester). In some cases, the mineralization has a spatial association with rocks of boninitic chemistry (e.g., Little Bay).

The mineralization occurs as massive, lenticular bodies or lodes, as disseminations, as sulphide veins and stringers, and as quartz-sulphide veins that are broadly concordant with the enclosing chlorite schist. The disseminated and stringer zones are generally considered to be feeders to the massive ores although they are in many cases not associated with, are spatially removed from, or occur laterally to, the massive lenses. In some cases, this separation can be demonstrated to result from faulting and/or transposition. However, in many cases, disseminated and stringer mineralization probably represents the full extent of the original mineralization.

The mineralization consists of pyrite, chalcopyrite, pyrrhotite, magnetite and lesser sphalerite, with local concentrations of gold and silver. High-grade chalcopyrite-rich stringers and veins are generally present in the footwall stringer and stockwork zones. Later deformation remobilized the chalcopyrite such that high-grade thickened-sulphide zones occur in the fold noses. Sphalerite-rich zones and lenses have been reported in the Little Deer Mine (West, 1972). The massive sulphides are generally deformed and in places contain laminations, colloform and framboidal textures, and slump structures.

Miles Cove Mine (NTS 2E/12 Cu012)

Location

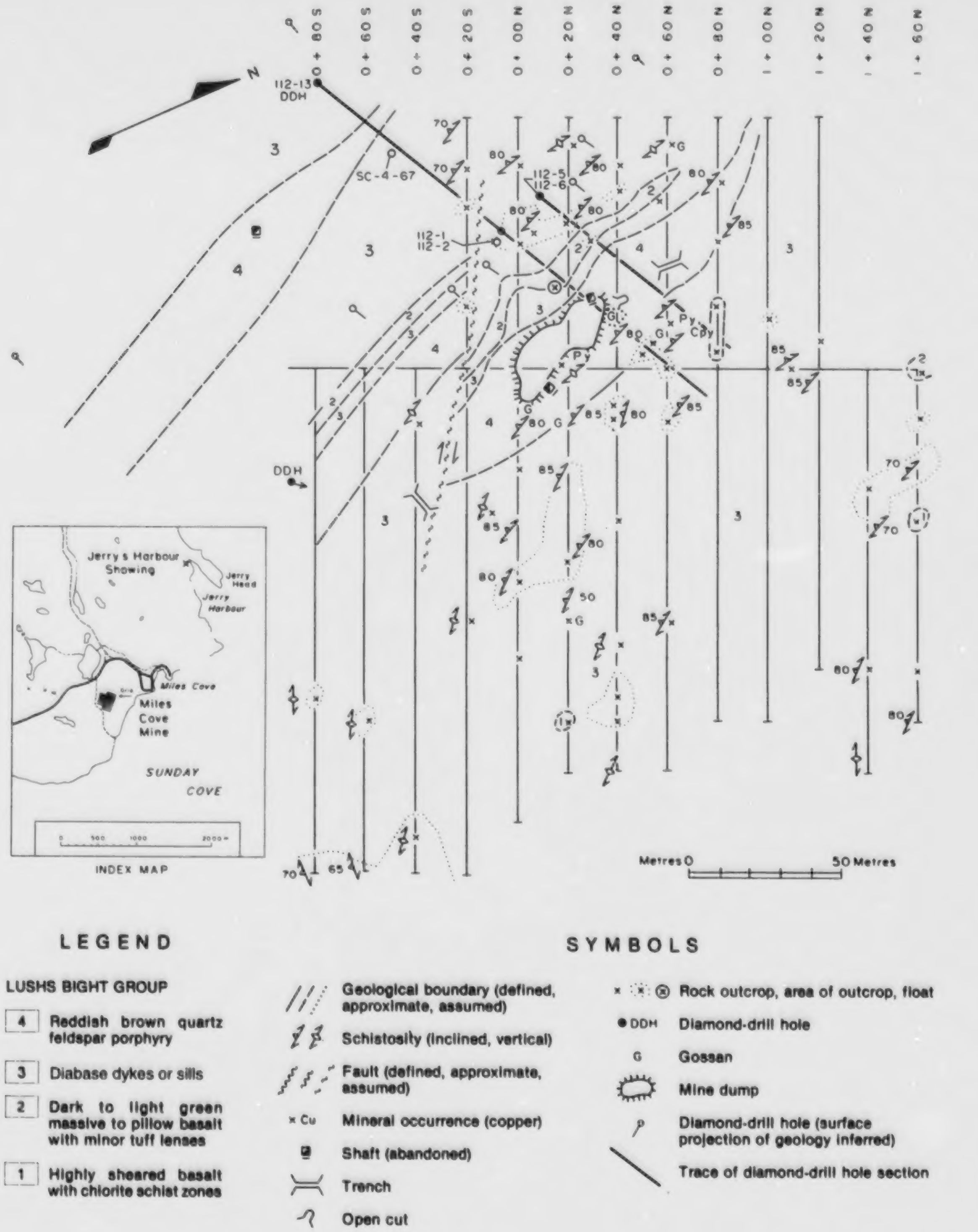
The deposit occurs on the east side of Sunday Cove Island about 500 m southwest of Miles Cove (Figure 53). A trail leads from the Miles Cove highway to the old mine site.

History of Development and Production

The area was originally granted to Phillip Cleary in 1894 (Cleary Fee Simple Mining Grant, Volume 1, Folio 47). The first exploration and development work appears to have been carried out by the Tharsis Sulphur and Copper Company, which optioned the property from Cleary in 1898. By the end of 1899 the company had mined and shipped 190 tonnes grading about 10 percent Cu. The ore proved unmarketable and the operation closed in 1899 (Martin, 1983). In 1935, an electrical survey was conducted on the property by Hans Lundberg. The results were not encouraging (Lundberg, 1935).

Douglas *et al.* (1940) reported that the old mine workings consisted of three shafts and two trenches. The No. 1 shaft was reported to be 17 m deep with a 23 m northeasterly directed drift from an unspecified depth. This drift intersected the main ore zone at 10.7 m at which point a winze was sunk for approximately 16 m in the ore. The No. 2 shaft was 9 m deep and approximately 43 m away from the No. 1 shaft. The location of the No. 3 shaft, which was also 9 m deep, is not known.

M.J. Boylen interests optioned the Fee Simple Grant on May 11, 1956. Ten Cate (1957) supervised ground magnetometer and self-potential (SP) surveys, geological mapping and diamond drilling. Drilling consisted of 13 holes totalling 1672 m, which outlined approximately 128 928 tonnes of 1.55 percent Cu (Table 9). The prospect also assayed 0.34 g/t Au and 12 g/t Ag (ten Cate, *op. cit.*).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0 + 60 S
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112-13 DDH
SC-4-67
112-5
112-6
112-1
112-2
DDH
Py
Cpy
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P
Jerry's Harbour Showing
Jerry Head
Jerry Harbour
Miles Cove
Miles Cove Mine
SUNDAY COVE
INDEX MAP
0 500 1000 2000 m
Metres 0
50 Metres
LEGEND
LUSHS BIGHT GROUP
4 Reddish brown quartz feldspar porphyry
3 Diabase dykes or sills
2 Dark to light green massive to pillow basalt with minor tuff lenses
1 Highly sheared basalt with chlorite schist zones
Geological boundary (defined, approximate, assumed)
Schistosity (inclined, vertical)
Fault (defined, approximate, assumed)
× Cu Mineral occurrence (copper)
Shaft (abandoned)
Trench
Open cut
SYMBOLS
Rock outcrop, area of outcrop, float
● DDH Diamond-drill hole
G Gossan
Mine dump
Diamond-drill hole (surface projection of geology inferred)
Trace of diamond-drill hole section

Figure 53. *Geology of the Miles Cove Mine property showing the location of the Miles Cove and Jerrys Harbour prospects, Sunday Cove Island (Howse and Collins, 1979).*

Table 9. Results of diamond drilling at the Miles Cove Mine by M.J. Boylen Engineering Company, 1957 (from ten Cate, 1957)

Hole No.	Footage From	Footage To	Intersection Width	Assay Results Cu %
112-1	195	201	6	0.74
	241	246	5	1.14
	265	289	24	2.29
112-2	298	311	13	1.16
	336	377	41	0.71
112-3	220	256	36	2.38
112-4	324	347	23	1.63
112-5	223	229	6	1.06
	234	237	3	1.25
	243	253	10	2.26
	268	273	5	1.13
112-6	248	253	5	0.91
	310	314	4	0.95
	323	326	3	4.10
112-7	237	240	3	0.98
112-8	347	330	3	3.33
112-9	175	189	14	1.34
	216	221	5	1.28
	265	270	5	1.42
112-10	237	245	8	1.51
	288	292	4	1.06
	336	341	5	2.95
112-11	258	268	10	1.76
	275	277	2	1.26
	283	298	15	1.96
112-13	174	182	8	1.00

BRINEX began an extensive period of exploration on Sunday Cove Island in 1963. Initial geochemical and geophysical activity identified two anomalous areas near the old workings—one in the vicinity of the old dumps and the other in the area of the trenches, about 360 m to the north (Bradley and Lilly, 1964). In 1965, reconnaissance ground magnetic, self-potential and EM-vertical loop geophysical surveys were carried out at the mine site (Lewis, 1965). Diamond drilling, consisting of 8 holes totalling 1233 m, was completed by BRINEX in 1967 to test the lateral extent of the zone outline by Boylen in 1957 (Strong, 1968).

Diamond drilling was subsequently recommended to determine the vertical limits of the deposits, however, no further drilling has been undertaken to date. Sections of some of the diamond drilling are given in Figures 54 and 55.

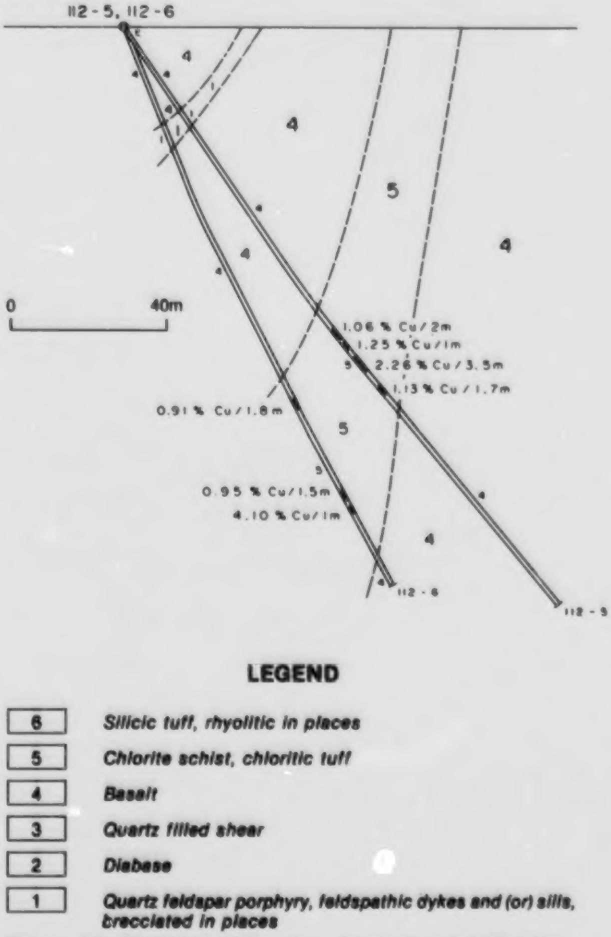

112-5, 112-6
4
1
4
5
4
4
0
40m
1.06 % Cu/2m
1.25 % Cu/1m
5
2.26 % Cu/3.5m
1.13 % Cu/1.7m
0.91 % Cu/1.8m
5
5
0.95 % Cu/1.5m
4.10 % Cu/1m
4
112-6
112-5
LEGEND
6 Silicic tuff, rhyolitic in places
5 Chlorite schist, chloritic tuff
4 Basalt
3 Quartz filled shear
2 Diabase
1 Quartz feldspar porphyry, feldspathic dykes and (or) sills, brecciated in places

Figure 54. *Diamond-drill section for diamond-drill holes 112-5, 6, Miles Cove Mine.*

Personnel from the then Newfoundland Department of Mines and Energy conducted a geological, geophysical and geochemical evaluation of the area in 1978 (Howse and Collins, 1979). They estimated the prospect to contain 199 800 tonnes of 1.45 percent Cu.

Local Geology and Mineralization

The deposit is hosted by chlorite schist developed within pillow lavas and dykes (Figure 53) a few hundred metres structurally above the sheeted dyke—pillow lava contact. Surface exposures consist of a 20- to 25-m-wide,

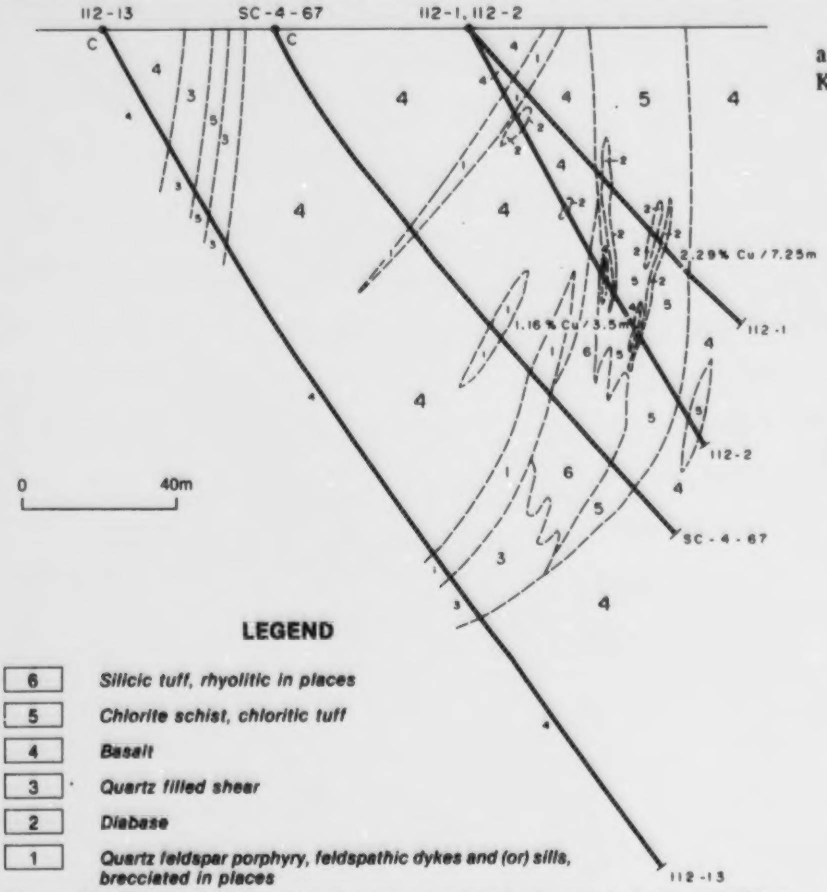

112-13
SC-4-67
112-1, 112-2
C
C
2.29% Cu / 7.25m
1.16% Cu / 3.5m
112-1
112-2
SC-4-67
112-13
0
40m
LEGEND
6 Silicic tuff, rhyolitic in places
5 Chlorite schist, chloritic tuff
4 Basalt
3 Quartz filled shear
2 Diabase
1 Quartz feldspar porphyry, feldspathic dykes and (or) sills, brecciated in places

Figure 55. *Diamond-drill section for diamond-drill holes 112-1, 2, 13, and SC-4-67, Miles Cove Mine.*

intensely chloritized, schist zone striking about 140° and dipping 80 to 85° west. Extensive quartz veins and knots cut the schist and are generally coplanar with the foliation. The chlorite schist grades into deformed, and lightly sheared, basaltic pillow lava. Small, round to oval quartz grains, possibly amygdules, are common in the chlorite schist below the pillow lava. Narrow beds or lenses of tuff are reported from this sequence. The sequence is intruded by diabase dykes and a felsic quartz-feldspar porphyry dyke occurs in the hanging wall. The schist is kinked and crenulated about a vertical north—south axial plane (Plate 21).

The mineralization consists of disseminations, blebs and stringers of pyrite and chalcopyrite, generally associated with quartz veinlets in the chlorite schist. Bands and lenses up to 1 by 20 m have been reported in underground workings (Douglas *et al.*, 1940). The ore zone intersected by the drift from the No. 1 shaft was described as follows by Douglas *et al.* (*op. cit.*) based on a private report of unknown date by A. Kowastch.

> ... "In the drift at the top of the winze the ore along the south wall is reported to be from 1 to 1½ feet thick and in addition there is a layer of "mixed ground" 1 foot wide. Down the winze the ore thickens rapidly till at a depth of 12 feet the ore is 3 feet thick, but then begins to thin again and at 24 feet it is cutt off in the hanging wall of a dyke. The winze was sunk through the dyke and at 44 feet (which may be the 60-foot level--O.N.R.) the ore was again cut in the footwall of the dyke. A second layer is reported in the footwall of the first band. North and south drifts were driven from the shaft (winze? at 60-foot level?--O.N.R.), developing an ore lens 70 feet long and a maximum of 3 feet thick. The grade was estimated at 9 to 12% copper, with about 2,000 tons in sight."

Minor gold and silver are also present. Magnetite occurs associated with the sulphides and as discrete lenses. The mineralized shear zone has a strike length of about 100 m and an average width of approximately 8 m; the depth of the mineralization has not been determined. There is no evidence of exhalative mineralization in the surface exposures and trenches, however, reports of the early workings indicate massive bands and lenses ranging in thickness from 0.3 to 1.0 m and up to 20 m long (Douglas *et al.*, 1940); they also report the presence of massive, banded, cupriferous pyrite on the ore dumps.

Jerrys Harbour (NTS 2E/12 Cu015)

Location

The showing occurs about 200 m northwest of Jerrys Harbour, on the eastern side of Sunday Cove Island (Figure 53). It can be reached by boat or footpath from the community of Miles Cove about 1.5 km to the south.

Plate 21. *Folded chlorite schist hosting disseminated and stringer sulphides, Miles Cove Mine, Sunday Cove Island.*

History of Development

The showing was originally granted to Phillip Cleary in 1894 (Cleary Fee Simple Mining Grant, Volume 1, Folio 24). There is no record of exploration or development prior to an electrical survey conducted by Hans Lundberg in 1935.

BRINEX began exploration about 1963 and conducted a self-potential survey in 1964 and trenching in 1968. The BRINEX activity culminated in 1968 with the drilling of four diamond-drill holes totalling 402 m.

Howse and Collins (1979) investigated the Jerrys Harbour showing in 1979 and conducted VLF-EM, ground magnetic, HLEM and geochemical soil surveys. The geochemical soil survey revealed a small copper anomaly in the vicinity of the showing.

Local Geology and Mineralization

The showing occurs in a narrow chlorite-schist zone developed in pillow basalts that have intercalated tuff and agglomerate lenses. Its position in the Lushs Bight Group stratigraphy is not clear; however, it is not at the sheeted dyke—pillow lava contact. The mineralization is exposed in a number of trenches having a visible strike length of 100 m trending about 135° and dipping approximately 70° west (Howse and Collins, 1979). The sulphide mineralization consists of a 1-m-wide band of predominantly pyrite and minor chalcopyrite. Stringers of pyrite and chalcopyrite associated with quartz veinlets and disseminations of pyrite and chalcopyrite occur within the chlorite-schist zone. The sulphides are generally concordant with the foliation. Two chip samples from the massive sulphides assayed 2.52 percent Cu, 0.26 percent Zn and 850 ppb Au (Howse and Collins, 1979).

A gossan zone of highly sheared, angular pyroclastic rocks (Howse and Collins, 1979) is exposed in a trench 50 m south of the mineralized zone; malachite and azurite staining is common.

North Paddock's Bight (NTS 2E/12 Cu016)

Location

The showing is located on the northeast side of Sunday Cove Island, immediately north of Paddock's Bight. It can be accessed by boat or footpath from Miles Cove located about 4 km to the south.

History of Development

There is no record of early exploration, development or production on this showing. However, three shafts and a number of small pits were sunk. Hans Lundberg included the area in his 1935 geophysical survey of Sunday Cove Island but failed to detect anomalies in the vicinity of the showing.

In 1956, M.J. Boylen optioned the various fee simple grants in the Sunday Cove Island area and briefly examined the showing (ten Cate, 1957). It was described as small with a limited amount of surface development work. A grab sample assayed 7.65 percent Cu, 0.52 oz Ag and 0.02 oz Au (ten Cate, 1957). BRINEX examined the prospect in 1964 (Bradley and Lilly, 1964) and followed up this work in 1968 with two diamond-drill holes totalling 268 m. In 1978, personnel from the then Newfoundland Department of Mines and Energy briefly examined the showing (Howse and Collins, 1979).

Local Geology and Mineralization

The showing occurs in chlorite schist developed from diabase dykes containing pillow screens. The mineralization is interpreted to have formed at the contact between sheeted dykes and pillow lava. The prospect consists of pyrite and chalcopyrite disseminations and narrow stringers concordant with the chlorite-schist zones.

Howse and Collins (1979) describe the local geology and mineralization near the three main shafts as follows:

"Shaft I Located approximately 250 m south of the point which marks the northernmost extremity of Paddox Bight. The water-filled shaft is about 2.5 m by 3.5 m and appears to be shallow. Rubble nearby consists of rusty, medium grained basalt with bands of chlorite schist. The schist hosts minor amounts of pyrite and chalcopyrite which occur in disseminated form and as narrow bands along fracture planes. The thickest chalcopyrite band observed measured 1.5 cm in width. The chlorite schist (schistosity) strikes 170° and dips 45° W. Pillowed basalt forms the hanging wall of the schist zone and the shaft appears to have been sunk along this contact. A select sample of the best mineralization assayed 12 per cent copper, 25 ppm lead, 0.12% Zn, and 0.2 ppm gold.

Shaft II Located about 40 m east of Shaft I, Shaft II measures 3 m by 0.5 m and is inclined down the dip of a shear zone in the basalt to an unknown depth. The basalt is pillowed and contains minor pyrite.

Shaft III Located about 50 m along the coast from Shaft II, Shaft III is partly filled with rubble, measures 3 m by 1 m and was also sunk on a shear zone which strikes 190° and dips 45° to 50° W. The footwall of the zone consists of massive basalt with prominent block fracturing. The fracture planes form a pattern with one set of planes parallel to the dip of the shear zone and the other forming acute angles with it. Only minor pyrite was observed in the zone.

Other small pits located about 20 m inland from the point apparently result from early attempts to explore minor amounts of sulphide (mostly pyrite) in sheared basalt."

Delaney Shaft (NTS 2E/12 Cu029)

Location

The prospect is located on the north side of Little Bay Arm about 200 m north of the old government wharf in St. Patricks.

History of Development

MacLean (1947) reported that early developmental work, consisting of a 23-m-vertical shaft with two crosscuts at the 12 or 15 m levels, was carried out around 1910 (Plate 22).

Plate 22. *Delaney Prospect shaft and dump, Little Bay Arm.*

The area was explored by BRINEX in the 1960s as part of their Halls Bay North Concession and the mineralized shear zone was probably trenched at this time. The trench, located 5 m from the old shaft, is approximately 1 m deep. In 1984, Canadian Nickel sponsored a B.Sc. thesis to study the geology and mineralization of the area (Anderson, 1984).

Local Geology and Mineralization

The mineralization occurs within chlorite schist developed in sheared pillow basalt. Diabase and feldsparphyric diabase dykes are also present. The chlorite-schist zone trends northwest but changes at its southern end to an easterly direction. The northern part of the chlorite-schist zone has a width of about 5 m and a mineralized width of about 2 m. Minor, localized, post-mineralization faults and contorted and fractured quartz veins are present.

Dilation zones, both syn- and post-faulting, were recognized by Anderson (1984) as a major area for mineralized concentrations in the Delaney prospect. The sulphide-bearing, quartz-carbonate and epidote stringers and veinlets filled openings in the shear zone created by folding, warping and tensional fracturing. These compressional—dilational structures were interpreted by Anderson (*op. cit.*) as the most important factors in localizing the sulphide mineralization. She described the mineralization as consisting of remobilized, fine-grained disseminations, lenses and fracture fillings associated with quartz and calcite developed within a shear zone. Also similar mineralization, but developed to a lesser extent, occurs in the host pillow basalts. Pyrrhotite, pyrite and chalcopyrite are the predominant sulphides but sphalerite is also present.

Anderson (1984) described the sulphide petrology and associated gold mineralization as follows:

> "Recrystallized, anhedral chalcopyrite is by far the most abundant constituting 75% of the sulphides present. It occurs as irregularly shaped masses and disseminations in a quartz-epidote assemblage. Lamellar twinning related to the deformation is common in most crystals....... . Chalcopyrite is found crystallizing along the edges of pyrite and pyrrhotite crystals....... . Sphalerite occurs similarly along grain boundaries and fractures.
>
> Pyrite is believed to exist in primary and secondary states. Those that crystallized first are found as distinct subhedral crystals. Secondary growth is related to recrystallization in the regions of deformed chalcopyrite. The lesser abundance of pyrite (e.g., chalcopyrite) is thought to be due to inversion of pyrite to pyrrhotite at temperatures of approximately 300°C where it remains in stable equilibrium.
>
> Pyrrohotite, the second most abundant sulphide, occurs primarily as anhedral porphyroblasts. They are found co-existing with the chalcopyrite and sphalerite. Recrystallized pyrrhotite present in chalcopyrite displays 120° triple junction with adjacent crystals .... The lower temperature, ferrimagnetic, monoclinic phase persists.
>
> Sphalerite is observed primarily as elliptical grains in chalcopyrite, coming in along fractures and the edges of crystals. Unmixing of chalcopyrite out of sphalerite is observed in bead-like exsolution texture present within some crystals, indicating that recrystallization took place at elevated temperatures.
>
> Tin and silver, identified through scanning electron microscopy, are present in trace amounts."

Anderson (1984) interpreted the mineralization to be exhalative, but remobilized during episodes of faulting. The country rocks were interpreted to be the source of the metals.

Four grab samples from the dump yielded an average of 0.54g/t Au (Table 10) but values of up to 4.8 g/t have been reported (Anderson, 1984). The gold occurs as native gold in quartz aggregates. There is no evidence of its solid solution with pyrite and chalcopyrite.

Table 10. Assays of grab samples from the Delaney mine dump (from Anderson, 1984)

Sample Number	Cu%	Au oz/ton
AN 30-83	2.40	0.0164 (0.56g/t)
AN 10-83	4.40	0.0180 (0.62g/t)
AN 03-83	9.00	0.0158 (0.54g/t)
AN 01-83	5.60	0.0128 (0.44g/t)

Little Bay Mine (NTS 2E/12 Cu030)

Location

The mine is located on the peninsula on the south side of Little Bay about 750 m southeast of the community of Little Bay. The area is accessible by road from the Little Bay highway.

History of Development and Production

The deposit was discovered in the spring of 1878 by Robert Colbourne of Wild Bight (Martin, 1983). The property owners, Dr. H. Eales of London and A. Guzman of the Betts Cove Mining Company, employed Baron Francis von Ellershausen, manager of the Betts Cove Mine, to manage the operation.

The mine was opened in 1878 and worked continuously until 1894, at which time production ceased due to market conditions and low reserves. During the initial stage of development, seven shafts ranging from 30 to 433 m in depth were sunk on the main mineralized zone. The principal and deepest shaft, inclined at about 80° south, was known as the Seary or Saralis shaft (Figure 56). In 1898, the Newfoundland Copper Company Limited operated and shipped a small quantity of ore from the mine, but ceased operation about 1901. They also conducted development work on the nearby Sleepy Hollow

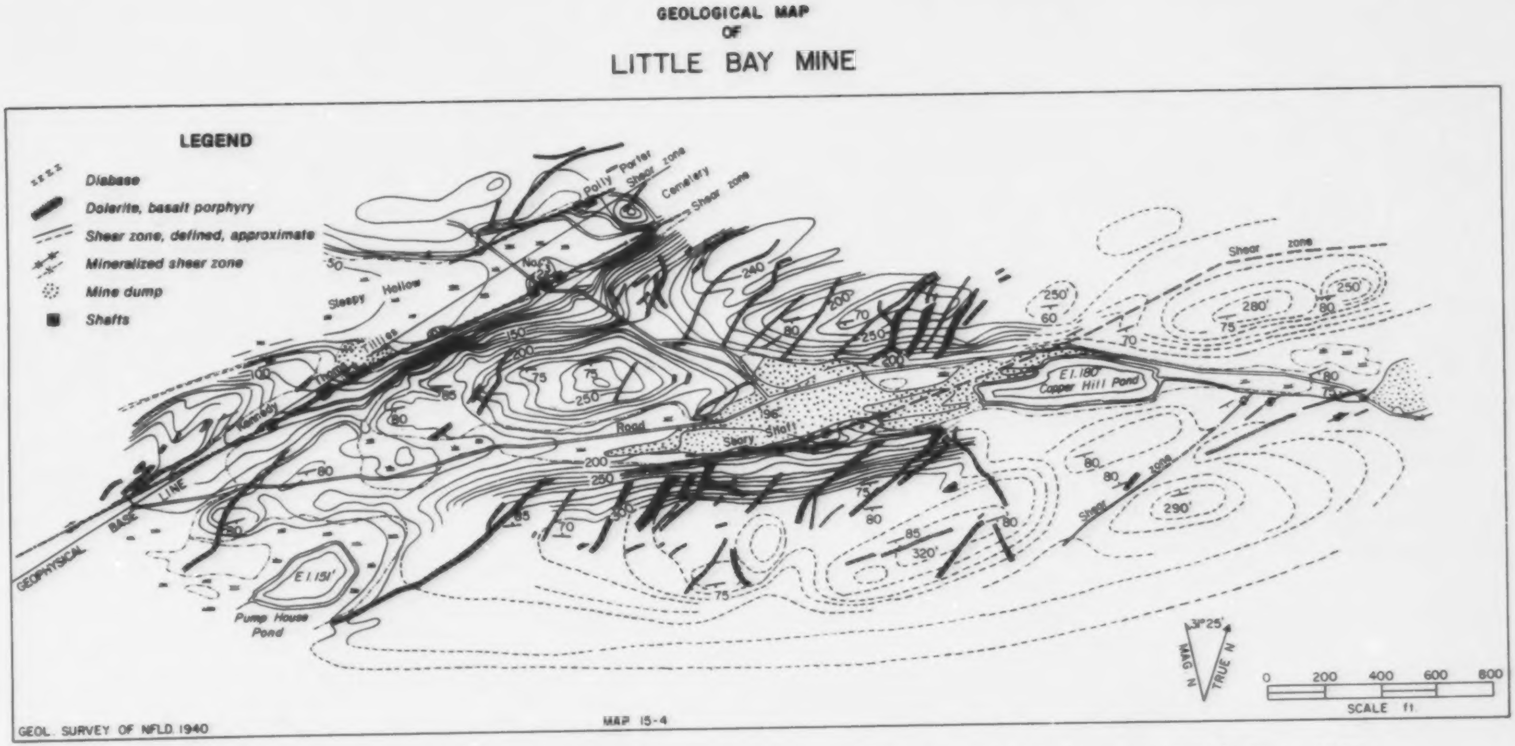

GEOLOGICAL MAP
OF
LITTLE BAY MINE
LEGEND
Diabase
Dolerite, basalt porphyry
Shear zone, defined, approximate
Mineralized shear zone
Mine dump
Shafts
Polly
Porter
Shear zone
Cemetery
Shear zone
Sleepy Hollow
Kennedy
Road
Seery Shaft
Copper Hill Pond
El.180'
El.151'
Pump House Pond
GEOPHYSICAL BASE LINE
Shear zone
MAG. N
TRUE N
3°25'
0
200
400
600
800
SCALE ft.
GEOL. SURVEY OF NFLD. 1940
MAP 15-4

Figure 56. *Geological map of the Little Bay Mine area showing dyke concentrations (Douglas* et al., *1940, and MacLean, 1947).*

deposit. The mine was again optioned in 1902, but was abandoned in 1904 when a large forest fire destroyed most of the town, mine workings and mine records. With the loss of the records it is impossible to determine the amount of ore mined, but it is estimated at 180 000 tonnes of 2.5 to 10 percent Cu (MacLean, 1947). The Newfoundland Exploration Syndicate unsuccessfully attempted to reopen the property in 1905. In 1906, the Pilley's Island Pyrite Company retimbered the Seary Shaft for about 150 m but then ceased operations.

In 1919, W.A. MacKay drove an adit from the south shore of Indian Bight, Little Bay, southward for 305 m toward the old mine without intersecting the main zone. The area was examined by the Reid Newfoundland Company Limited (Hatch, 1920), who concluded that "... Conditions existing in unexplored intruded areas of chloritic schist are very favourable to the formation of orebodies. ... there is very little question but that other pay orebodies will be located." Diamond drilling by the Little Bay Drilling Syndicate on behalf of the Reid Newfoundland Company in 1921 and 1922 delineated mineralization and determined its strike length to be about 275 m, of which approximately 180 m had been mined to a depth of about 425 m. One hole, 90 m west of the workings, intersected 7 m of 2.35 percent Cu.

Extensive sampling of the Little Bay mine dumps was carried out in 1926 by the firm Poillon and Poirer (Douglas *et al.*, 1940). They estimated that 196 000 tonnes averaging 1.48 percent Cu remained on the dumps. During the period 1938 and 1939, H.J. MacLean examined the mine site in detail as part of his examination of the geology and mineral deposits of the Little Bay area (MacLean, 1947).

In July 1955, New Highridge Mining Company optioned the property from Reid Newfoundland Company and in December O'Brien Gold Mines became a partner in the venture; surface exploration and diamond drilling began immediately. By November 1956, about 52 holes, totalling about 12 800 m, had been completed. This work indicated, after allowing a 20 percent dilution, an estimated 2 368 000 tonnes of ore averaging 2.1 percent Cu to a depth of 472 m.

The option to purchase the property was exercised on December 4, 1957, and the property was then sold to Atlantic Coast Copper. In 1958, the old workings were dewatered to the 305 m level and underground exploratory work carried out. A new 3-compartment shaft was begun and by 1959 was completed to a depth of 320 m, with levels at 76, 122, 167, 213, 259 and 305 m. Lateral development was done on the 105 m level, and about 1220 m of drifting and crosscutting was done on the 167, 213 and 259 m levels. A geophysical survey was carried out on surface to test the eastern extension of the ore zone. A decision was made to place the mine in production at a milling rate of 907 tonnes/day (1000 tons/day).

Plate 23. *Little Bay Mine (ca. 1960). 23a: View of headframe; 23b (page 87): view of mining complex from tailings pond.*

In 1960, the shaft was deepened by about 76 m providing for a 7th level at 350 m. The mill and ancillary buildings (Plate 23) were completed, and in 1961 a loading dock, concentrate storehouse and some houses were erected. Mill equipment was installed in the spring of 1961, and production from mine dumps began in May 1961, and from underground workings in July. However, production was hampered by excessive dilution due to the old workings and poor ground conditions. In 1963, the shaft was deepened to 442 m and level development started on the 350 and 411 m levels. As a result of further diamond drilling, the shaft was deepened to 478 m and a level was established at the depth of 457 m in 1964. The shaft was further deepened in 1965 to 627 m and additional levels established at the 503 and 549 m. In 1966, a 385 m crosscut was driven to the North Zone on the 213 m level

Plate 23b. *Little Bay Mine (ca. 1960). View of mining complex from tailings pond.*

because underground exploration indicated the presence of two ore shoots which, although narrow, yielded grades well above mine average. The North Zone, known as "Sleepy Hollow", had been prospected and developed around 1898. The company began development on the 503 and 549 m levels at year's end; however, ground conditions below the 457 m level were found to be poor, and diamond drilling below the 503 m level indicated only minor sulphides. In 1967, the company conducted magnetometer, self-potential, vertical loop EM and VLF-EM geophysical surveys and further diamond drilling.

In 1968, limited surface diamond drilling and extensive underground drilling were completed without encouraging results. By the end of 1968, reserves had declined to an estimated 267 000 tonnes averaging 1.02 percent Cu. The crown pillar, weakened by mining activity, collapsed (Plate 24) and mining ceased on October 31, 1968. Mill clean-up and underground salvage operations were completed December 31, 1969, and all shaft and raise openings on surface were sealed. The property has since changed ownership a number of times.

The production for the period 1961-1969 was 2 571 977 tonnes of 0.8 to 2 percent Cu and 195 kg Au (Table 11).

Local Geology and Mineralization

The Little Bay Mine occurs in a northeast-trending, steeply southeast-dipping chlorite-schist 'shear zone' developed in variolitic and locally quartz amygdaloidal pillow basalt. Variolitic, boninitic, pillow basalts occur immediately to the southwest of the mine. Diabase dykes are common, locally up to 40 percent (Figure 56), most of the dykes are feeders to the pillow sequences. Sheeted diabase dykes occur at Little Bay below the mineralized zone, and are separated from it by a fault. Younger diabase and amphibole-porphyritic dykes are also present. The chlorite schist is gradational into less-deformed pillow lavas.

The pillows average 0.5 m in diameter but range up to 1 m. White and green interpillow chert is locally present. The pillow lavas are highly epidotized in the cores, and the

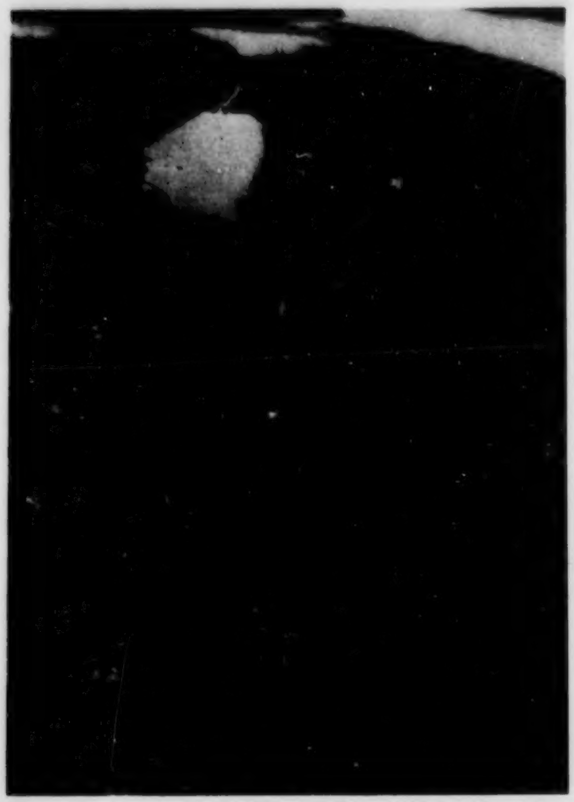


Plate 24. *Aerial view looking northeast of Little Bay Mine glory-hole in the foreground (ca. 1988).*

rims are chloritic. A bleached and silicified zone of pillow basalt and breccia occurs approximately 1.5 km along strike on the coast to the northeast. Proximal to the 'shear zone' the pillow rims become chloritized schist enveloping an epidotized core. Within the shear zone the rocks are essentially chlorite schist (with quartz and sulphides) and epidote is almost totally absent.

The chlorite-schist zone is ellipsoidal and has a mineralized length of about 300 m, a maximum width of 25 m, and a depth of 600 m. Small-scale drag folds plunge 45 to 70° northeast. The "Sleepy Hollow" or North Zone is hosted by a parallel *en echelon* shear zone approximately 300 m to the northwest of the main chlorite-schist zone.

The Little Bay deposits occur as massive lenses and pods, as disseminations, as veins and veinlets of pyrite and chalcopyrite and as sulphide-bearing quartz veins within the chlorite schist (Plate 25). The mineralogy is predominantly pyrite and chalcopyrite with wurtzite, magnetite, marcasite, pyrrhotite, sphalerite and covellite present in minor amounts (Gale, 1969). Quartz and chlorite form the principal gangue minerals and they also occur as inclusions in the sulphides (Plate 26). Native arsenic was reported by V.S. Papezik (Gale, 1969).

Gale (1969) described the Little Bay deposits as consisting of several mineralized lenses or zones hosted by chlorite schist. These steeply plunging lenses or zones are of varying lengths, have an average width of 8 m, and pinch and swell. The mineralizatoin occurs as massive to semi-massive sulphide pods of predominantly pyrite and chalcopyrite grading up to 10 to 12 percent Cu and as narrow ramifying veinlets and disseminations of pyrite and chalcopyrite within the chlorite schist averaging 1 percent Cu. The chalcopyrite veins are up to 2.5 cm wide and in places contain only trace pyrite and quartz. Within the massive pods the pyrite occurs as irregular shaped grains and as smaller euhedral grains veined by, and partly embedded in, chalcopyrite. The embedded pyrite grains are usually rounded and somewhat embayed. The wurtzite veins embay and form a thin shell around the pyrite grains. Marcasite is intergrown with the pyrite grains and has sharp euhedral boundaries. Chalcopyrite is the only abundant economic sulphide mineral and occurs as large irregular masses within the sulphide-rich pods.

The sulphide-bearing quartz veins consist of about 60 percent quartz and 40 percent pyrite embedded in the quartz. The pyrite grains are generally semirounded and slightly to strongly fractured, forming narrow parallel bands in the quartz veins. Quartz and chalcopyrite fill and replace the fractures. Chalcopyrite is not abundant and occurs as tiny veinlets and stringers chiefly along fractures in the quartz, but also replacing pyrite along fractures (MacLean, 1947).

In the caved area at the old mine site, the mineralized zone is approximately 10 m wide and consists of massive sulphide pods, veins and disseminations of sulphides within the chlorite schist. Lenses or pods, 40 cm to 1 m thick, of coarse, granular grey pyrite and minor chalcopyrite in a quartz-rich gangue are also present. These pods have a streaky banding defined by pyrite and quartz—pyrite layers. Disseminated euhedral pyrite, thin pyrite veinlets and minor quartz veins in chlorite schist are commonly associated with the pods. Within the chlorite schist are small, irregular patches of white sericite(?) schist that appear to grade into chlorite schist. The massive sulphide pods or zones, up to 5 m thick, consist of sulphide bands (or veins) 1 to 15 cm thick with interbanded chlorite schist 0.5 to 5 cm thick. The sulphides consist mostly of pyrite and minor chalcopyrite and pyrrhotite. Chalcopyrite increases toward the top of these massive zones. Some of these sulphide bands crosscut the chlorite schist and many appear to be veins that are transposed coplanar with the chlorite schist. The hanging-wall contact is generally marked either by a dyke or by disseminated and veined pyrite in chlorite schist.

Table 11. Production data from the Little Bay Mine for this period, 1961 to 1969 (Source: MODS files)

Year	Tons Ore Milled	Tons/ Day	Grade (%)	Tons Concentrate	Copper Content (lbs.)	Gold Content (oz.)
1961	196 081	827	1.252	8 790	4 165 022	715
1962	351 668	964	1.310	16 480	8 498 796	1 295
1963	376 403	1 031	0.911	12 100	6 419 878	819
1964	317 529	868	0.893	9 931	5 322 450	665
1965	292 023	800	1.101	10 862	6 103 787	543
1966	318 735	873	1.301	13 487	7 903 174	674
1967	341 322	935	1.125	12 344	7 307 698	617
1968	346 289	946	1.962	10 895	6 406 585	544
1969	295 070	971	.835	7 994	4 621 653	399
TOTAL	2 835 120 tons (2 571 977 tonnes)			102 997*	56 797 456*	6 271 (195 kg)

* Includes 93.6 tons of clean-up concentrate containing 48 413 lbs. of copper.

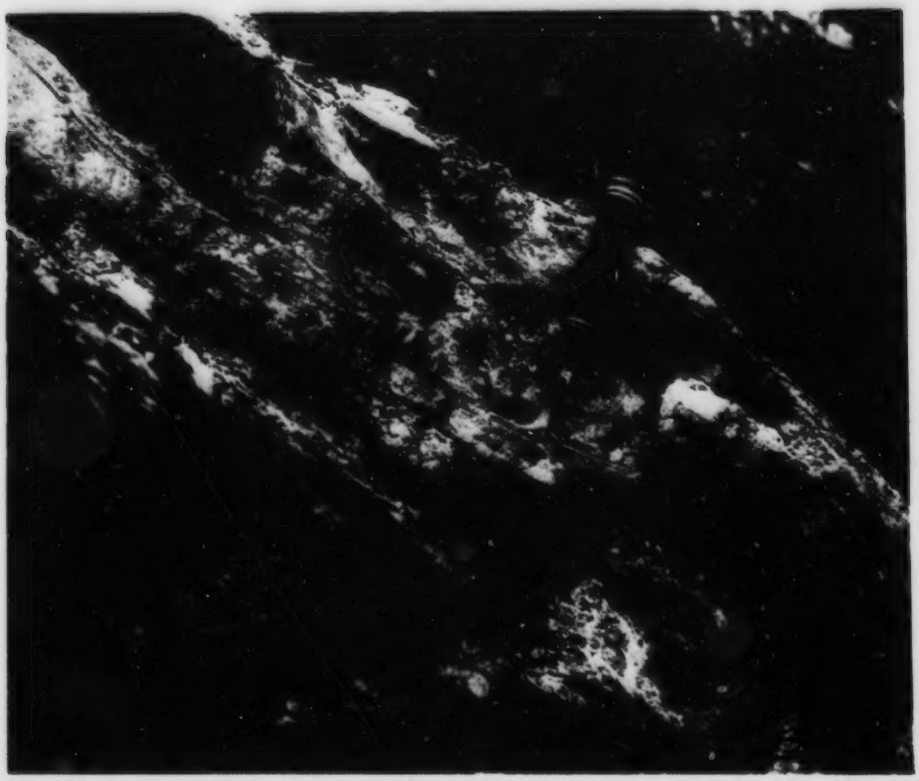


Plate 25. *Pyrite and minor chalcopyrite lens within chlorite schist, Little Bay Mine glory hole.*

Sleepy Hollow (North Zone) (NTS 2E/12 Cu031 and Au003)

Location

The old workings are situated in a linear valley southeast of the community of Little Bay Mine and immediately northwest of the Little Bay Mine. They can be reached by road and trail from the Little Bay Mine area and Little Bay.

History of Development and Production

Much of the exploration record is taken from MacLean (1947). The 'Sleepy Hollow' or North Zone area was first mined by the Newfoundland Copper Company

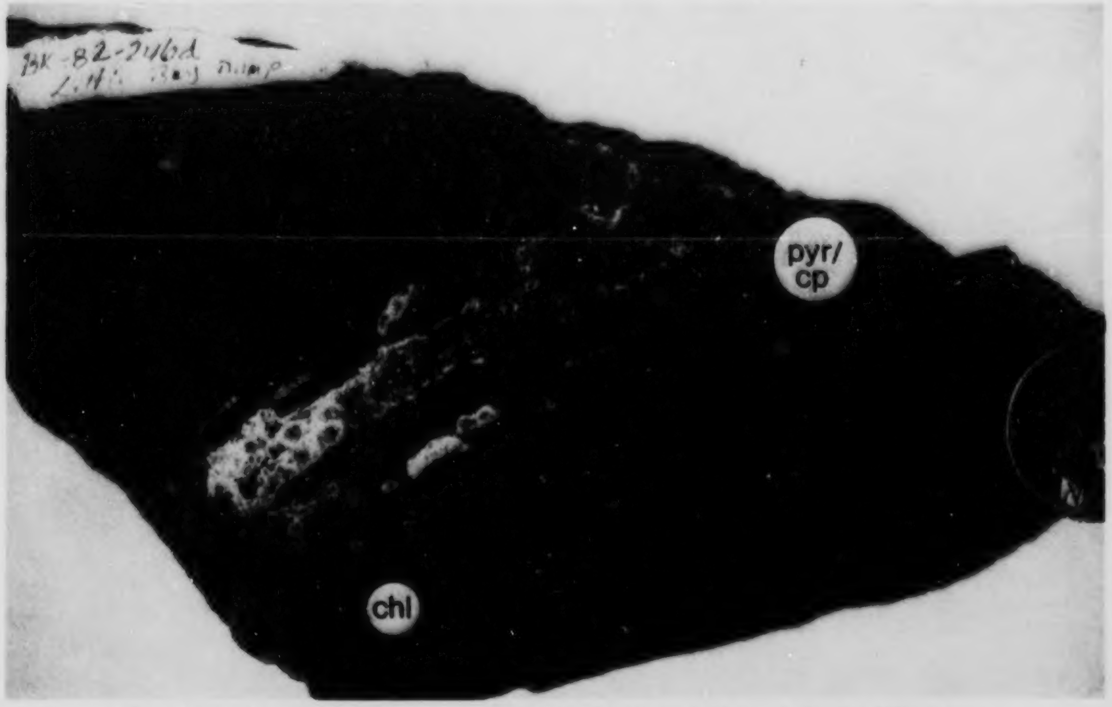


Plate 26. *Chalcopyrite-pyrite vein with black chlorite inclusions, Little Bay Mine dump.*

Limited, which sank two shafts to a depth of 61 m on the property in 1898. There are no records of the grades or tonnage mined; however, Douglas *et al.* (1940) report that small grab samples of ore from the dumps assayed greater than 5 percent copper.

In 1906, the area was drilled by the Pilley's Island Pyrite Company while they were exploring and retimbering the Seary shaft at the Little Bay workings. W.A. McKay sank seven shafts on the property in 1919; thus a total of 9 mine shafts ranging in depth from 15 to 61 m were sunk in this area (Figure 56). Eight of these shafts were sunk on the same shear zone; these shafts include, from southwest to northeast, Kennedy, Thoms (2), Tillies (2), and Numbers 1, 2 and 3. The Polly Porter was sunk on a smaller shear zone to the north. It is connected to Mackay's adit, a 305 m adit driven southward toward the Little Bay Mine from Indian Bight, and passing just to the east of the Polly Porter shaft. Douglas *et al.* (1940) briefly examined the Sleepy Hollow area and conducted a small geophysical survey in the vicinity of the old mine workings. This survey failed to indicate the presence of any new ore bodies.

In 1962, BRINEX drilled a 145-m diamond-drill hole in the Sleepy Hollow area for Atlantic Coast Copper Limited. Further diamond drilling was conducted by Atlantic Coast Copper Limited between 1964 and 1966. Underground exploration from the Little Bay Mine intersected the two narrow mineralized zones with high copper grades. A crosscut was driven out to and through the two zones from the 213 m level of the Little Bay Mine in 1966 by Atlantic Coast Copper Limited. Recent exploration work in the Polly Porter - Cemetary areas has revealed significant gold mineralization within the chlorite-schist zone (Burton, 1984).

Local Geology and Mineralization

The Sleepy Hollow mineralization occurs in a chlorite-schist zone that is parallel and *en echelon* to the Little Bay Mine, approximately 300 m to the northwest. It may be a structurally repeated sequence. The pillow lava is generally variolitic and commonly contains interpillow green chert and, in places, jasper. As at the Little Bay Mine, diabase dykes are common and locally constitute up to 40 percent of the rock type. The following description is extracted from MacLean (1947).

> "There are four shear zones in en echelon arrangement in the immediate area; the two most westerly contain the Sleepy Hollow deposits. They are roughly parallel to the main Little Bay Mine shear zone.

The largest shear zone has a length of about 2,700 feet. It strikes approximately N 45°E and dips 80°S. Eight prospecting shafts are sunk on this zone over a distance of 1,200 feet along the strike. Shafts Nos. 1, 2, and 3 are sunk on the same schist band, spaced about 20 feet apart. At the surface the schist is fairly barren. According to local report these shafts have a depth of 60 to 100 feet and have cross-cuts and drifts. The ore is in the form of lenses in the schist and consists of pyrite and chalcopyrite. Five hundred feet southwest from Shafts Nos. 1, 2, and 3, are five more shafts sunk along the same shear zone. A couple of these shafts, referred to on maps as Thoms Shafts, are reported to be 200 feet in depth and have enough drifting to prove ore over a length of 300 feet with a width of 5 to 10 feet. The shear zone can be traced some 1,500 feet southwest from the most westerly shaft; this end of the schist zone, where exposed on the surface, consists of barren chlorite schist with only lightly disseminated pyrite. From the tiny drag folds in the chlorite schist near Thoms Shafts, the movement is considered to be largely horizontal, the north side moving northeast relative to the south side.

The smallest shear zone has a length of about 500 feet. It strikes N 45° E, and dips to 80°S to vertical. This zone contains one shaft, the Polly Porter, which has a depth of about 70 feet and is the only non-flooded shaft in the area; this shaft drains through MacKay Adit. MacKay Adit runs due south for about 400 feet, passing 10 feet to the east of the bottom of Polly Porter Shaft with which it is connected, and then heads magnetic south for approximately 600 feet. Its inner end is about 200 feet north of the west end of the Little Bay Mine shear zone. The MacKay Adit crosses no ore zone, either near the Polly Porter Shaft or where it crosses the schist (zones) just east of Shafts Nos. 1, 2, and 3. These schist bands, which cross the adit, carry only a minor amount of disseminated pyrite. At the surface, the Polly Porter zone shows much unmineralized schist. The shaft, in depth, reveals lens-like deposits of cupriferous-pyrite replacements typical of the Little Bay Mine area; there are barren schist zones between the lenses of ore.

Post-mineralization fault movements along the schist zone are indicated by minor slickensides."

In the mid-1980s, the Little Bay—Sleepy Hollow area was explored for gold associated with both the massive sulphides and the chlorite-schist zones. Grab samples from the Polly Porter area (NTS 2E/12 Au003) assayed 4.29 and 6.17 g/t gold with a channel sample of 3.22 g/t over 1.4 m (Burton, 1984). One grab sample from the Cemetary Zone (Figure 56) assayed 26.57 g/t gold although the average was 1.03 g/t gold (Burton, 1984).

Shoal Arm and Little Bay Head (NTS 2E/12 Cu032 and Cu033)

Location

The Shoal Arm and Little Bay Head showings consist of a number of mineralized areas extending from the coastline south of Little Bay Head for 1 km southwest toward Shoal Arm, Southern Arm. Access to the area is by trail or boat from Beachside.

History of Development

Early developmental work was reported to have been undertaken on the prospects in 1906 (Murray and Howley, 1918). The area was examined by MacLean in 1938 and 1939 (Douglas *et al.*, 1940; MacLean, 1947).

MacLean (1947) described the development on the prospect as consisting of a group of six shafts about 670 m N 60° E from the east end of Shoal Arm, Southern Arm and one shaft 884 m east of the others on the cliff-top close to the south shore of Little Bay Head. These shafts were collectively called the Little Bay Head prospect. Subsequently, however the main group became known as the Shoal Arm showing, and only the most easterly was referred to as the Little Bay Head showing. Four shafts of the Shoal Arm showing are atop a ridge paralleling the strike of the country rocks. Two more shafts are about 68 m to the south on another shear zone. All the shafts are greater than 8 m in depth and are flooded to the collar.

Local Geology and Mineralization

The mineralization occurs within chlorite schist developed in pillow lava accompanied by locally abundant diabase dykes. Feldsparphyric diabase dykes and grey quartz-feldspar, felsite porphyry are also present. The felsite porphyry dykes vary from 0.25 to 2 m in width, trend northeast—northwest and are vertical.

The pillow lavas contain epidotized varioles. Elongated quartz grains in the chlorite schist probably represent amygdules. Grey to whitish-green interpillow schist is present locally. The mineralization occurs as disseminations and stringers, often associated with quartz and calcite veinlets. Pyrite, chalcopyrite, pyrrhotite, sphalerite, arsenopyrite and marcasite are present. Lightly disseminated mineralization also occurs along the contacts of the felsic dykes at some distance from the shafts.

Whalesback Mine (NTS 12H/9 Cu001)

Location

The Whalesback Mine is located 3.5 km north of the community of St. Patricks. A gravel road leads from the Little Bay highway north to the mine site.

History of Development and Production

The Whalesback orebody was discovered in 1879, and Adolph Guzman of the Betts Cove Mining Company sold the property to the Newfoundland Consolidated Copper Mining Company in December 1880 (Martin, 1983). MacLean (1947) reported that early exploration activity consisted of a number of trenches and an 18-m-deep shaft sunk in the hanging wall. There appears to have been no ore shipped from the area and MacLean (*op. cit.*) indicated that no ore was exposed in the surface workings.

The Whalesback—Little Deer area was included in the extensive Halls Bay Concession that was granted to BRINEX in 1957. A joint agreement between BRINEX and the Anglo-American Corporation led to an exploration program in the Whalesback area. Between February 1960 and March 1962, diamond drilling outlined approximately 2.7 million tonnes of 1.8 percent Cu down to the 275 m level. Encouraging results from further geological, geochemical and geophysical surveys justified underground exploration. Later in 1962, a surface plant was erected and a 3-compartment shaft was sunk to a depth of 15 m.

A mining lease covering 590.8 hectares (1460 acres) was granted to BRINEX in November 1962 by the Newfoundland Government. In 1963, shaft-sinking was completed to approximately 332 m. Development levels were established at the 68, 130, 190, 244, and 297 m levels (Figure 57). Extensive underground diamond drilling and lateral development in 1963 and 1964 led to a production decision. During 1964, underground work continued and Whalesback Pond was partially drained via a 335 m tunnel. The 1800 tonne/day mill (2000 ton/day) (Plate 27), completed in August 1965, went into production on October 8, 1965. Reserves above the 297 m level were 3 600 000 tonnes of 1.5 percent Cu. By the end of 1969 reserves were reduced to 1 677 000 tonnes of 1.06 percent Cu. Further diamond drilling in 1970 below the 335 m level failed to discover economic-grade mineralization, and by the end of 1970 reserves had fallen to 900 000 tonnes of 1 percent Cu. Low copper prices and lower ore grades resulted in heavy losses for the company in 1971. Reserves at the close of 1971 had declined to 300 000 tonnes grading 0.8 percent Cu. A major cave-in, unintentionally induced by blasting, breached the surface (Plate 28) and mining operations ceased in July 1972. The total production for the Whalesback Mine was 3 793 581 tonnes of approximately 1 percent Cu (Table 12).

Local Geology and Mineralization

The Whalesback orebody is contained within a chlorite schist in pillow lavas (Figure 58). These pillow lavas are low-potassium tholeiites (Fleming, 1970) characterized by an assemblage of epidote, albite, chlorite, actinolite, calcite and quartz containing relict augite and saussuritized plagioclase (Kanehira and Bachinski, 1968). Varioles are locally present. Interpillow material consists of greenish-grey chert, chloritized mafic pyroclastic rocks and sulphide. In the Whalesback area, the pillow lavas trend dominantly 060°, dip steeply to the northwest or are overturned to the southeast. The pillow lavas are cut by a variety of dykes and sills that range from gabbroic (related to the volcanism) to various younger porphyry dykes (Kanehira and Bachinski, 1968). The porphyry dykes are unsheared and basically unmineralized even within the chlorite-schist zone. The dykes are generally parallel or subparallel to the shear fabric, however, in places both the schist and the orebody are cut by the dykes (Kanehira and Bachinski, *op. cit.*). Late movement within the 'shear zone' has broken and boudinaged many of the dykes.

The chlorite-schist zone hosting the orebody trends 065° and dips steeply to the northwest. It is approximately 720 m long and has a maximum width of 120 m. Kanehira and Bachinski (1968) suggested that the zone pinches out to the southwest and is faulted to the northeast.

There is a gradual change in the rocks as the chlorite-schist zone is approached. The pillows are increasingly sheared and elongated along shear planes (Kanehira and Bachinski, 1968), although relict pillow shapes can be distinguished across the zone. Mineralogical changes accompany the deformation, for example, augite disappears and chlorite increases in abundance as the locus of deformation is approached. Epidote also decreases and is generally absent from the chlorite-rich zones. Albite laths are replaced by quartz aggregates (Kanehira and Bachinski, *op. cit.*). The centre of the schist zones is marked by a chlorite-quartz assemblage containing minor sphene and muscovite.

Geochemical studies (Bachinski, 1977) show a progressive depletion or leaching of Na and Ca as the chlorite-schist zone hosting the Whalesback orebody is approached and traversed (see Figure 50). There appears to be a dramatic increase in Fe and S and erratic increases in K going from the country rocks into the chlorite-schist

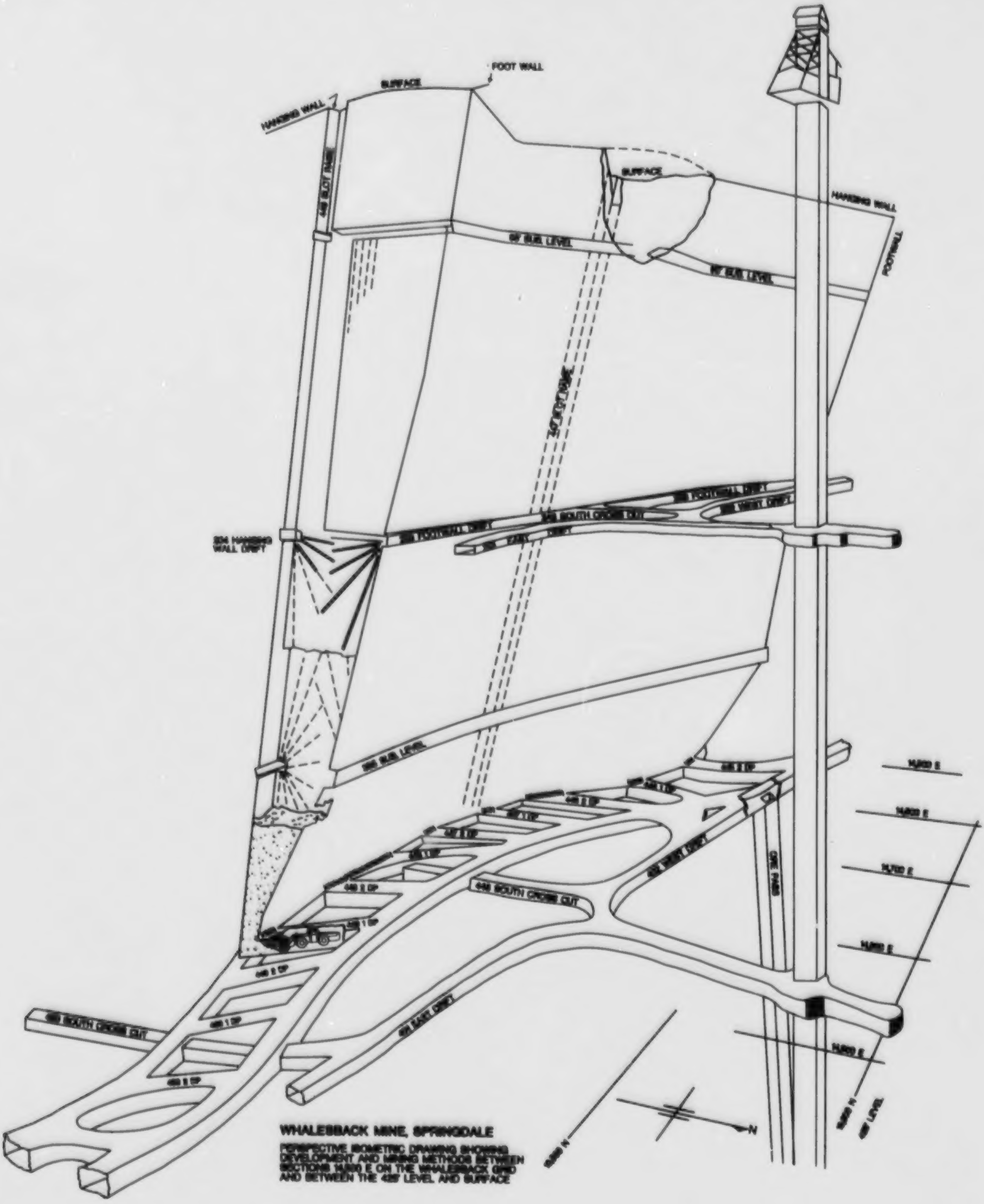

FOOT WALL
SURFACE
HANGING WALL
SURFACE
HANGING WALL
SUB LEVEL
SUB LEVEL
FOOTWALL
HANGING WALL DRIFT
FOOTWALL DRIFT
SOUTH CROSS CUT
EAST DRIFT
WEST DRIFT
SUB LEVEL
440 SOUTH CROSS CUT
SOUTH CROSS CUT
ORE PASS
WEST DRIFT
EAST DRIFT
N
WHALESBACK MINE, SPRINGDALE
PERSPECTIVE ISOMETRIC DRAWING SHOWING
DEVELOPMENT AND MINING METHODS BETWEEN
SECTIONS E ON THE WHALESBACK GRID
AND BETWEEN THE 425' LEVEL AND SURFACE

Figure 57. *Perspective isometric drawing of part of the Whalesback Mine showing development and mining methods between the 130 m (425 ft5.) level and surface (adapted from drawing by BRINEX personnel).*

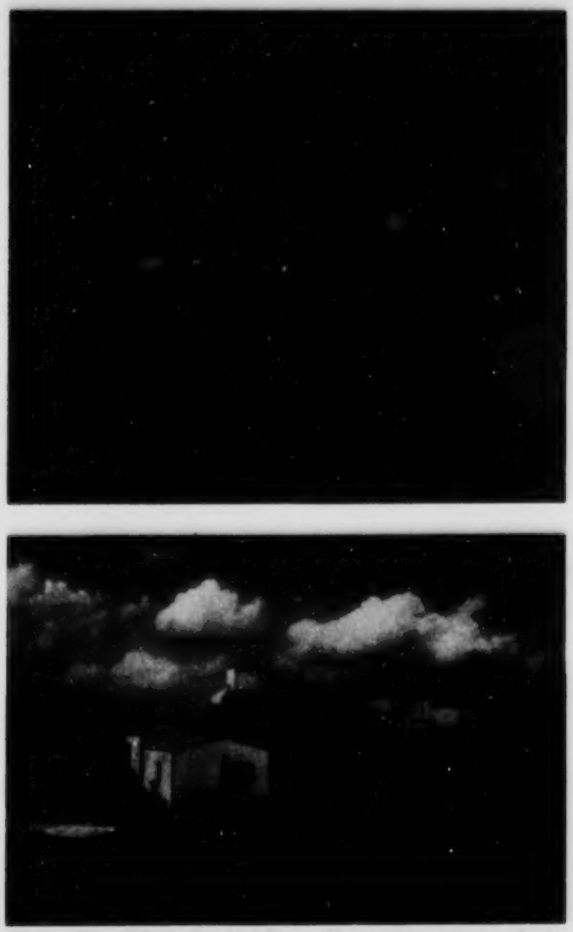


Plate 27. *Whalesback Mine. Top: area view of the Whalesback Mine site; Bottom: Whalesback mill about 10 years after mine closure (ca. 1983).*

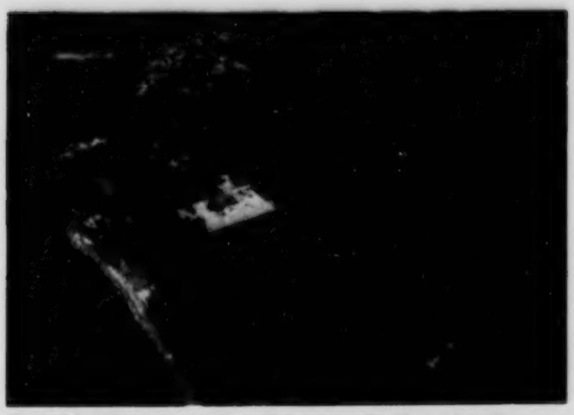


Plate 28. *Whalesback Mine. Remnants of mill and headframe on left, tailings pond on extreme left, cave-in in centre (ca. 1988).*

Table 12. Whalesback Mine production for the period 1969 to 1971 (Source: MODS files)

Year	Tons Milled	Cu %	Cu (lbs)
1965	181 966	-	4 567 000
1966	644 128	1.10	13 217 000
1967	658 285	0.85	10 403 571
1968	725 867	0.98	13 290 000
1969	718 490	0.86	11 270 000
1970	690 972	-	10 263 000
1971	562 000	-	7 761 000
Totals	4 181 708 tons (3 793 581 tonnes)	-	70 771 571

zone. These chemical changes are attributed to hydrothermal alteration.

The Whalesback orebody constituted 25 to 35 percent by volume of the chlorite-schist zone, and was confined to the central and hanging-wall portions of the zone. Ore textures such as banding and streaking of sulphides in massive ore, crushed pyrite and localized development of pressure shadows, are attributed to shearing stress that postdated the original sulphide ore formation (Kanehira and Bachinski, 1968). The economic concentration of sulphides appears to occur at the site of maximum disruption within the chlorite-schist zone suggesting extension remobilization during subsequent movement in the zone.

The following description of the Whalesback orebody is from Kanehira and Bachinski (1968):

> "Disseminated and massive ores are distinguished: the former are predominant and consist of moderately foliated to highly contorted zones of discontinuous to anastomosing stringers and blebs of chalcopyrite and pyrite, which grade into the pyrite-rich outer portions of the shear zone; the latter consists of pods, veins and dike-like sulphide bodies generally along shear planes. Massive ores vary from less than 1 foot to about 4 feet in width. Compositional banding within the massive ore is relatively common and is a function of chalcopyrite-rich and pyrite-rich layers. More rarely, pyrrhotite occurs as streaks parallel to the banding. Disc-shaped fragments of chloritized wall rocks are present in the ore and are commonly arranged parallel to the walls. Locally, the massive veins pinch and swell, behaving in such cases akin to the dike rocks. In places sulphides, especially chalcopyrite, have been remobilized and deposited in necks of dike

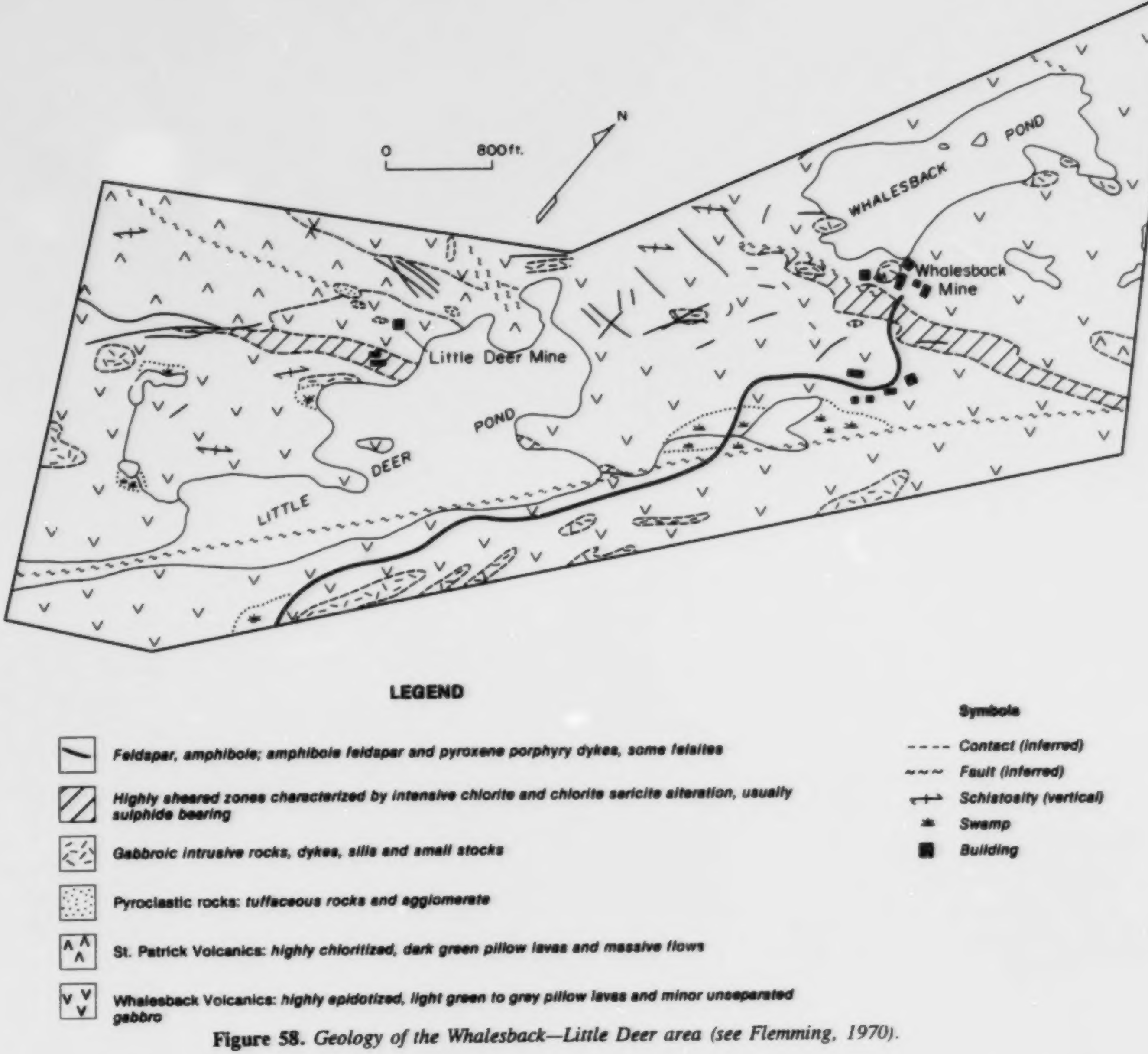

0
800 ft.
N
WHALESBACK
POND
Wholesback
Mine
Little Deer Mine
LITTLE
DEER
POND
LEGEND
Feldspar, amphibole; amphibole feldspar and pyroxene porphyry dykes, some felsites
Highly sheared zones characterized by intensive chlorite and chlorite sericite alteration, usually sulphide bearing
Gabbroic intrusive rocks, dykes, sills and small stocks
Pyroclastic rocks: tuffaceous rocks and agglomerate
St. Patrick Volcanics: highly chloritized, dark green pillow lavas and massive flows
Whalesback Volcanics: highly epidotized, light green to grey pillow lavas and minor unseparated gabbro
Symbols
Contact (inferred)
Fault (inferred)
Schistosity (vertical)
Swamp
Building

Figure 58. *Geology of the Whalesback–Little Deer area (see Flemming, 1970).*

> boudins. The ore boundaries tend to be assay walls. The hanging wall of the ore is relatively sharp in contrast to the footwall, where the assay boundary tends to be irregular. The pyrite envelope is more extensively developed in the footwall, which is stratigraphically lower in the volcanic sequence. The ore zone is parallel to the strike of the shear zone, but dips steeply south, in contrast to the shearing, which dips steeply north. It plunges about 50° southwest."

In order of decreasing abundance, the ore minerals are pyrite, chalcopyrite, pyrrhotite, sphalerite, mackinawite, pentlandite, magnetite, cubanite, galena and ilmenite accompanied by the sugergene alteration products marcasite, covellite and goethite (Kanehira and Bachinski, 1968). Gangue minerals are chlorite and quartz accompanied by minor muscovite, carbonate, sphene, albite and epidote.

Kanehira and Bachinski (1968) concluded that the present distribution of sulphides is a result of remobilization due to structural deformation. The mineralization, they reasoned, must be in part post-volcanic, pre-shearing and pre-metamorphism because dykes, which cut the pillow lavas, chlorite schists and sulphide lenses, are metamorphosed. An extremely altered granodiorite—diorite body intersected at depth by drilling was interpreted by Kanehira and Bachinski (*op. cit.*) as the heat source for the mineralizing fluids.

The deposits are herein considered to be volcanogenic massive sulphides enclosed by a chlorite envelope that represents a hydrothermal alteration zone.

Little Deer Mine (NTS 12H/9 Cu002)

Location

The mine site is located northwest of the community of St. Patricks, about 1 km southwest of the Whalesback Mine. It can be reached via the Whalesback Mine access road.

History of Development and Production

The Little Deer deposit was discovered by Falconbridge Nickel Mines Limited in 1952 (West, 1972). The company investigated the property by diamond drilling, but dropped the ground after obtaining discouraging results.

BRINEX first examined the area in 1955 as part of its detailed prospecting and geochemical soil surveys in the Whalesback area. Extensive geological mapping and magnetic, electromagnetic (EM), self-potential (SP) and geochemical surveys detected anomalies extending from the discovery site beneath Little Deer Pond. In 1962, 25 diamond-drill holes totalling 4555 m outlined a mineralized zone about 244 m long and averaging 8 m wide to a maximum depth of 180 m. Further drilling in 1963, consisting of 12 holes, delineated an easterly extension of the zone at depth and a parallel occurrence beneath the pond. Extensive drilling between 1965 and 1968 proved sufficient grades and tonnage for mining as part of the operation at Whalesback. Estimated reserves were 285 000 tonnes at 1.53 percent Cu. In 1969, a 1044-m-long drift was driven from the 244 m level of the Whalesback Mine to the Little Deer orebody. A secondary exit and airway were also developed. In 1970, proven reserves at Little Deer were 154 200 tonnes of 2.3 percent Cu and indicated reserves were 36 000 tonnes of 3 percent Cu. At the time of closure of the Whalesback operation in 1972 reserves at Little Deer were 130 000 tonnes of 1.6 percent Cu.

In 1973, Green Bay Mining Company leased the property and, collaring in the footwall, drove a 329 m decline to the orebody (Plate 29). The ore zone was accessed by crosscuts and inclines (Figure 59; Baumgartl, 1974). In 1974, the company produced 75 000 tonnes of ore before market conditions forced closure of the operation. Reserves at the cessation of mining in 1974 stood at 210 200 tonnes grading 1.53 percent Cu.

Plate 29. *Little Deer decline (ca. 1983).*

Local Geology and Mineralization

Peters (1967) was the first to describe the geology of the Little Deer deposit. He stated that the mineralization was hosted by highly contorted quartz—sericite—chlorite schists located in a shear zone parallel to and 900 m west of the shear zone hosting the Whalesback Mine. Peters (*op. cit.*) suggested that the schistose zone may have followed a stratigraphic horizon of felsic tuff and

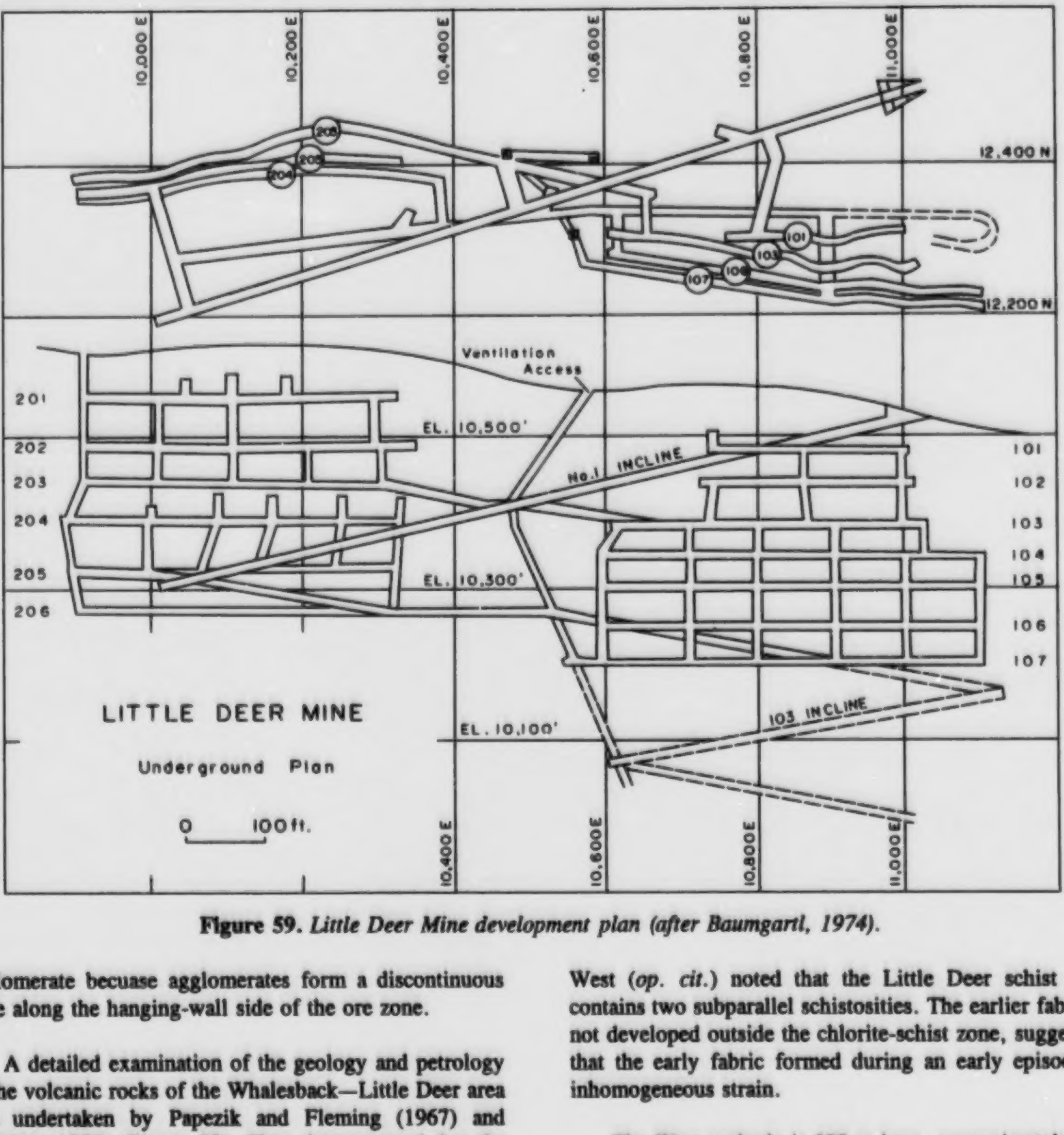

10,000 E
10,200 E
10,400 E
10,600 E
10,800 E
11,000 E
12,400 N
12,200 N
204
205
101
103
106
107
Ventilation Access
201
202
203
204
205
206
EL. 10,500'
No.1 INCLINE
EL. 10,300'
101
102
103
104
105
106
107
LITTLE DEER MINE
Underground Plan
0 100 ft.
EL. 10,100'
103 INCLINE
10,400 E
10,600 E
10,800 E
11,000 E

Figure 59. *Little Deer Mine development plan (after Baumgartl, 1974).*

agglomerate becuase agglomerates form a discontinuous zone along the hanging-wall side of the ore zone.

A detailed examination of the geology and petrology of the volcanic rocks of the Whalesback—Little Deer area was undertaken by Papezik and Fleming (1967) and Fleming (1970) (Figure 58). They demonstrated that the host mafic volcanic rocks are low-potassium tholeiites. The structure and ore genesis of the Little Deer Mine were examined by West (1972) as part of an M.Sc. thesis. West (*op. cit.*) described the ore as being hosted by a chlorite-schist (the Little Deer schist zone) that trends 065° and dips 70° to 75° southeast. The chlorite-schist zone is approximately 1050 m long and 60 m wide. This zone pinches out to the southwest and terminates against the Little Deer fault (Figure 58), a splay of the Davis Pond fault system, which passes under Little Deer Pond. The sulphide mineralization is contained in two zones termed the West orebody and the East orebody, which are separated by 170 m of barren and bleached chlorite schist. West (*op. cit.*) noted that the Little Deer schist zone contains two subparallel schistosities. The earlier fabric is not developed outside the chlorite-schist zone, suggesting that the early fabric formed during an early episode of inhomogeneous strain.

The West orebody is 200 m long, approximately 3 m wide, and at least 120 m deep, with its downward extension open. It trends 065°, dips 76° south and plunges 30° east. The sulphides vary from medium grained, massive to disseminated and consist of pyrrhotite, chalcopyrite and minor pyrite and sphalerite in a brecciated quartz-sericite schist. Chlorite schist occurs as randomly oriented fragments within the massive sulphides (Plate 30) and as host to the disseminated sulphides.

The East orebody consists of two lenses of pyrrhotite, chalcopyrite, pyrite and sphalerite and abundant quartz, connected by zones of disseminated sulphides in quartz-sericite schist. The first lens trends 065°, dips 50°

Plate 30. *Black chlorite fragments within pyrite—chalcopyrite, Little Deer Mine.*

north, plunges 50° west-northwest and measures 30 m long, 3 m wide and 60 m deep. The second lens trends 117°, dips 68° south, plunges 50° south-southwest and measures 50 m long, 3 m wide and at least 100 m deep. It is open at depth. Peters (1967) and Kennedy and DeGrace (1971) suggested that the two lenses occur on opposite limbs of a fold. The two lenses of the East orebody consist of medium-grained pyrrhotite and chalcopyrite grading into predominantly pyrite and minor sphalerite toward the southwest. The pyrite—sphalerite-rich lenses generally contain fine-grained pyrite interlaminated with sheared, epidotized, chlorite schist containing disseminated pyrite (West, 1972). The laminae parallel the trend of the lenses. Hanging-wall contacts are sharp but the footwall contains disseminated chalcopyrite, pyrite and pyrrhotite veinlets up to 30 m from the massive sulphide zones. Banding is defined by pyrite-quartz and quartz-lithic fragments and bands. It is interpreted to be tectonic and appears in part to be cataclastic (Plate 31).

West (1972) suggested that the Little Deer, Whalesback and Little Bay mines all occur on the southern limb of a major anticline, close to the axial zone. The chlorite-schist zones, which host the Little Deer and Whalesback deposits, were interpreted to be generated as *en echelon* faults arranged along the Little Deer fault, a splay of the Davis Pond fault system.

Rendell-Jackman Prospect (NTS 12H/9 Cu003)

Location

The prospect is located about 1.5 km south of King's Point and can be reached by a trail from the Harry's Harbour road.

History of Development and Production

The Rendell-Jackman prospect, discovered in 1909 by Esau Burt of King's Point, consists of two lenses informally termed the North and South lenses (Figure 60). It was claimed by Robert Rendell of St. John's and James M. Jackman of Tilt Cove (Martin, 1983). Development work commenced in November 1909 and by 1910 a vertical shaft (Shaft #1) had been sunk on the North Lens to a depth of 40 m, with two short drifts extending along strike. By 1912 approximately 1456 tonnes of ore with an average grade of 4 percent Cu had been mined (Stewart, 1912). Proven reserves at this time were reported at 11 000 tonnes at an unspecified grade (DeGrace, 1971). Two shafts and further drifting on the South Lens were undertaken in 1930 (DeGrace, 1971). Shaft #3, the most southerly, was sunk to a depth of about 18 m at an inclination of 40° northeast (MacLean, 1947). Shaft #2 is about 54 m deep and is connected with Shaft #3 on the 10 m level (MacLean, 1947). It was estimated that the dumps (Plate 32) from this work contained about 2000 tonnes of ore averaging 1 percent Cu along with minor values of Ag and Au (Bruce, 1952). Hans Lundberg Limited conducted an EM survey of the mine site in 1935-36.

Plate 31. *Tectonic banding defined by quartz-pyrite and quartz-lithic fragments, Little Deer Mine.*

The Geological Survey of Newfoundland drilled five holes on the property in 1939. Although failing to intersect commercial ore grades, all holes intersected light- to heavy-pyrite mineralization and minor, narrow chalcopyrite-rich bands in chlorite schist.

Kontike Mines Limited drilled 10 diamond-drill holes on the prospect in 1955 without encountering ore. In 1959, an Anglo American—BRINEX joint venture explored the area and conducted a stream-sediment survey. This survey identified a copper anomaly in the vicinity of the old mine. In 1966-67, BRINEX carried out self-potential (SP), induced-potential (IP) and magnetometer surveys and drilled 4 holes in the vicinity of the old mine. This drilling showed the dimensions of the northern lens to be 70 by 296 m and the southern lens to be 35 by 209 m.

Local Geology and Mineralization

The prospect is hosted by chlorite schist developed in mafic volcanic rocks. DeGrace (1971) described the schist zones as discontinous and developed more or less parallel to the volcanic layering. The host sequence is interpreted to lie on the south limb of an overturned anticline.

There are two styles of mineralization occurring within the same schist zone (MacLean, 1947). The first, in the vicinity of Shaft #3 on the South Lens, consists of both massive beds of pyrite up to 1.8 m thick and disseminated pyrite in the chlorite schist. The ore was described as having a banded appearance (Plate 33) defined by layers of fine-grained sphalerite and coarse- to fine-grained pyrite and "wisps of unreplaced chlorite schist" (MacLean, 1947), which were interpreted to be parallel to the schistosity. The second, less common type, is a 'nodular' chalcopyrite-rich zone along with minor pyrite and is found in the North Lens. The following description of the mineralogy is taken from MacLean (1947).

> "The most common variety is the massive pyritic ore represented on the dump from Shaft No. 3, and the less common type is the nodular chalcopyrite in chlorite schist represented on the dump from Shaft No. 1. Both are sulphide replacement deposits in chloritic schist with only a little introduction of non-metallic gangue minerals.

The pyritic type consists of fairly massive pyrite beds up to 6 feet in thickness along with disseminated pyrite replacing chlorite schist. The minerals are, in order of abundance, pyrite, chalcopyrite, quartz, sphalerite, and calcite, along with unreplaced wisps of chlorite schist. This ore usually has a banded appearance; the banding is due partly to thin sphalerite-rich layers, partly to coarse and fine layers of pyrite grains, and also due to unreplaced shreds of chlorite schist; the

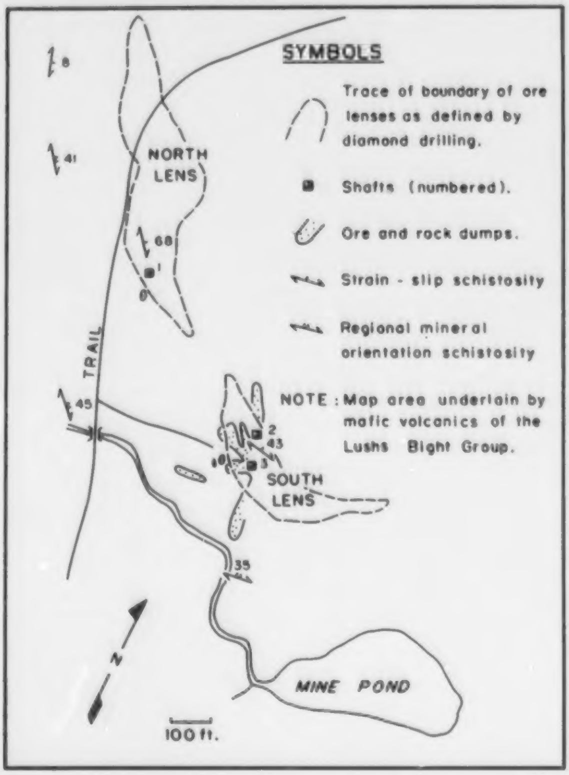

SYMBOLS
Trace of boundary of ore lenses as defined by diamond drilling.
Shafts (numbered).
Ore and rock dumps.
Strain - slip schistosity
Regional mineral orientation schistosity
NOTE : Map area underlain by mafic volcanics of the Lushs Bight Group.
NORTH LENS
SOUTH LENS
TRAIL
MINE POND
N
100 ft.
8
41
68
1
45
2
43
3
35

Figure 60. *Location and setting of the Rendell-Jackman prospect.*

Plate 32. *Waste and ore dumps at the Rendell-Jackman property (ca. 1983).*

> banding is parallel to the schistosity of the replaced chlorite.
>
> The nodular chalcopyrite ore usually occurs as nodules or lenses of chalcopyrite up to 4 inches in diameter with chlorite schist wrapped around the nodules, and with tiny veinlets of chalcopyrite crosscutting the chlorite schist. A small amount of pyrite occurs as individual cubes embedded in the chalcopyrite. Some of the larger pyrite grains are rounded and are veined by chalcopyrite. A few tiny blebs of chalcopyrite-rich ore was introduced along and replaced sections of the schist zone which were not already heavily replaced by pyrite. The massive pyritic beds of ore contain some bands of chalcopyrite-rich ore a few inches in thickness....."

DeGrace (1971) described the Rendell-Jackman prospect as follows:

> "The Rendell-Jackman showings are located in schist zones, and the shape and relative positions of the ore lenses as defined by diamond drilling suggest that they are in the same schist zone. The southern lens is located in the hinge of the major F_3 fold in the map area and is apparently folded by it. Stratigraphically the mineralization is in a section of tuffs. This is inferred from the laminated appearance of the massive sulphides, the presence of rare apparently boudinized lenses of jasper in the mineralized zone ......, and the presence of a section of tuffs above and below the schist zone.
>
> Macroscopically, the sulphides are laminated on a scale of 1 cm or less with respect to sulphide concentration and grain size, and in that respect superficially resemble the surrounding tuffs. In polished section no sedimentary features are visible and in fact the pyrite bands appear to be isoclinally folded into minor structures to which the strain-slip schistosity is axial planar. Pyrite and sphalerite apparently precede chalcopyrite in the sulphide paragenesis."

DeGrace (1971) indicated that economically important massive sulphides only occur in shear zones with chalcopyrite being enriched in the hinges of later folds. The sulphides, he suggested, were originally stratabound and pretectonic with respect to the shear zones. The sulphides were later remobilized within the shears.

McNeily (NTS 12H/9 Cu004)

Location

The old mine workings are located on the east side of Southwest Arm approximately 9 km northeast of the community of King's Point, just south of Colchester Pond (Figure 61). The site can be reached by a rough gravel road leading from the Harry's Harbour road to the Colchester area.

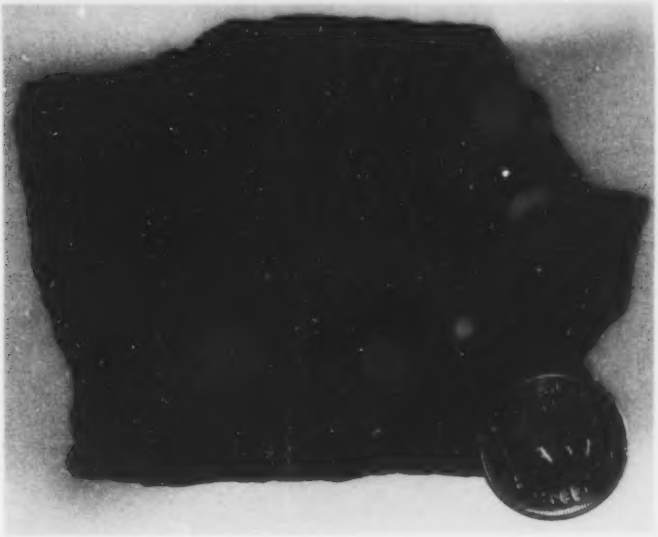


Plate 33. *Banded pyrite and chalcopyrite—sphalerite, Rendell-Jackman prospect.*

History of Development and Production

Mineralization was discovered in the fall of 1891 by an unemployed miner who, upon attempting to record his claim the following spring, discovered that A.W. McNeily, a politician, had already laid claim (McNeilly Fee Simple Grant) to his find (Martin, 1983). Mining at the McNeily property was begun in 1892 by Andrew Whyte, the Little Bay mine manager (Martin, 1983). Whyte, along with mine Captain John R. Stewart and a group of miners, cut a road from the Colchester Mine to the McNeily site and set up a crushing plant. About 600 tonnes of ore were mined and crushed before problems at the Little Bay Mine forced them to abandon the operation. The ore remained at the site until John Stewart hauled the ore to the Little Bay Mine in 1897 (Martin, 1983). In 1898, the Tharsis Sulphur Company shipped an unknown amount of ore from the McNeily property and mined and hoisted more ore that remained on the mine dumps (Martin, *op. cit.*).

The original McNeily Mine workings were described by H.J. MacLean (Douglas *et al.*, 1940) as consisting of a number of pits, two main shafts and three prospecting shafts (Figure 62). The following description is taken from Douglas *et al.* (1940):

> "The two main shafts are reported to be 56 and 120 feet in depth with a connecting drift, and drifts off at several levels; they are inclined about 80° to the south and are sunk in a 15-foot zone of chlorite schist, striking N 25 to 30°E and dipping 80° SE., which has a mineralized width of from 2 to 5 feet. About three cargoes of ore were shipped from the two shafts."

A third prospecting shaft about 120 m to the south of the main shafts is over 30 m deep.

A geophysical survey of the McNeily area was carried out by Hans Lundberg in 1935 (Lundberg, 1935). Detailed mapping, sampling and prospecting were conducted by G.S.W. Bruce for Falconbridge Nickel Mines in 1951. A chip sample collected over 1.5 m on the main zone, near one of the old shafts, assayed 1.59 percent Cu, trace Au and 0.08 oz/ton Ag (Gibbs, 1967). Bruce estimated that approximately 760 tonnes of ore averaging 1.83 percent Cu remained on the ten mine dumps located on the McNeily property (Gibbs, 1967).

M.J. Boylen Engineering acquired the McNeily Mine as part of the Colchester package in 1962. Extensive magnetometer, magniphase electrical surveys, soil sampling, geological mapping and diamond drilling consisting of three holes totalling 410 m was carried out in 1962 and 1963 (Brown, 1963). Colchester Mining Company was formed by M.J. Boylen in 1966 and further exploration of the property was carried out (Gibbs, 1967). The property was optioned to Cerro Mining Company in 1969 (McArthur, 1971) and they conducted extensive geological, geochemical and geophysical surveys of the Colchester option. Cerro drilled 9 holes totalling 1409 m; however, the option was dropped after work during the 1970 field season failed to discover significant mineralization (see Table 13).

Colchester Mining Company drilled two holes on the McNeily property in 1972 but intersected only low copper values over short distances. In general, it appears that the mineralization varies from <0.5 to <4 percent Cu over short intervals. The McNeily Fee Simple Grant reverted to the Crown and came open for staking in 1987.

Local Geology and Mineralization

The prospect occurs in altered and schistose volcanic rocks near the southern contact with the Colchester Pluton.

Brown (1963) stated that the McNeily and Colchester mines are concentrated along two well-developed fault zones, trending north 30° east and north 60° east. Movement along the faults produced schistose zones and intense fracturing.

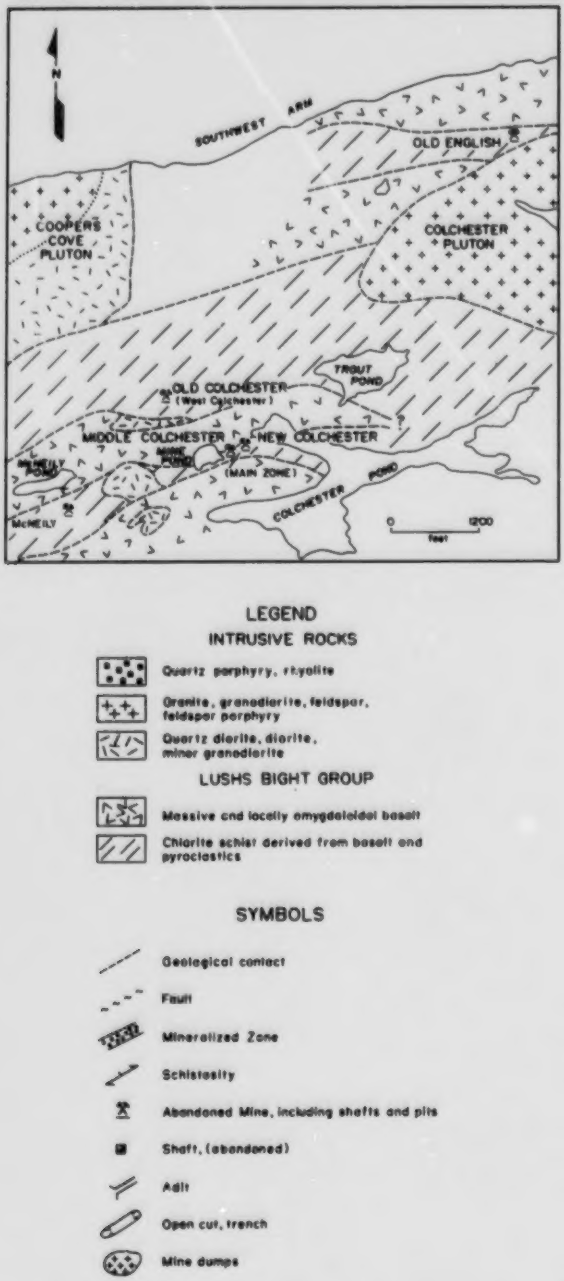

N
SOUTHWEST ARM
OLD ENGLISH
COOPERS COVE PLUTON
COLCHESTER PLUTON
TROUT POND
OLD COLCHESTER (West Colchester)
MIDDLE COLCHESTER
NEW COLCHESTER
McNEILY POND
(MAIN ZONE)
COLCHESTER POND
McNEILY
0 1200 feet
LEGEND
INTRUSIVE ROCKS
Quartz porphyry, rhyolite
Granite, granodiorite, feldspar, feldspar porphyry
Quartz diorite, diorite, minor granodiorite
LUSHS BIGHT GROUP
Massive and locally amygdaloidal basalt
Chlorite schist derived from basalt and pyroclastics
SYMBOLS
Geological contact
Fault
Mineralized Zone
Schistosity
Abandoned Mine, including shafts and pits
Shaft, (abandoned)
Adit
Open cut, trench
Mine dumps

Figure 61. *Location and geological setting of mineralization in the Colchester–McNeily area.*

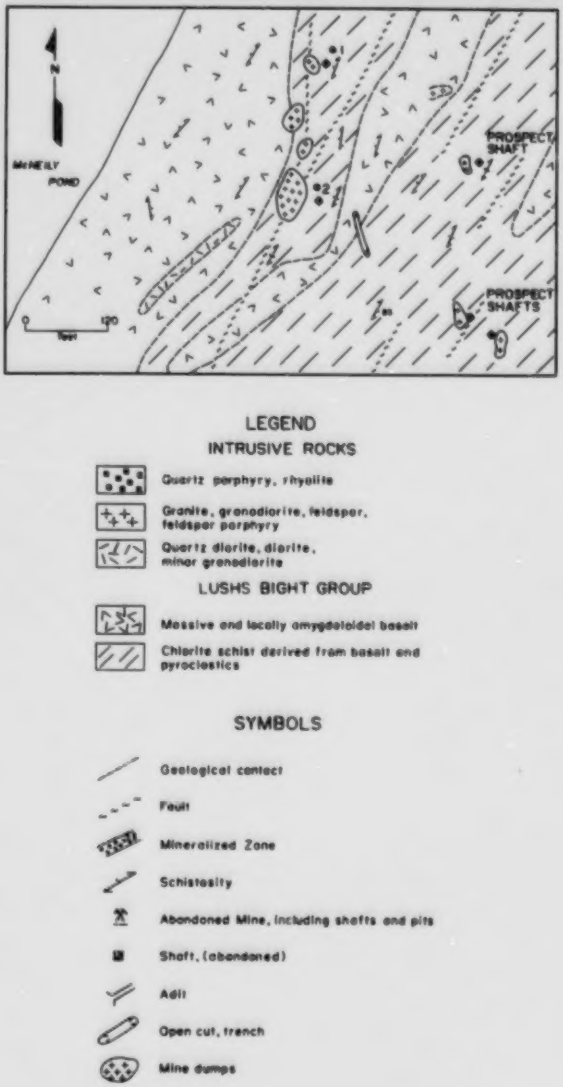

N
McNEILY POND
0 120 feet
PROSPECT SHAFT
PROSPECT SHAFTS
1
2
LEGEND
INTRUSIVE ROCKS
Quartz porphyry, rhyolite
Granite, granodiorite, feldspar, feldspar porphyry
Quartz diorite, diorite, minor granodiorite
LUSHS BIGHT GROUP
Massive and locally amygdaloidal basalt
Chlorite schist derived from basalt and pyroclastics
SYMBOLS
Geological contact
Fault
Mineralized Zone
Schistosity
Abandoned Mine, including shafts and pits
Shaft, (abandoned)
Adit
Open cut, trench
Mine dumps

Figure 62. *Geology map of the McNeily area (see McArthur, 1971).*

The mineralization was described by J.H. MacLean (Douglas *et al.*, 1940) as consisting of fine-grained magnetite and interstitial quartz cut by chalcopyrite and rare pyrite veinlets. The massive ore, consisting of chalcopyrite and rare pyrite veinlets, locally has a banded appearance and contains minor amounts of pyrrhotite and sphalerite. MacLean described microscopic gold as "veining a crushed zone between two pyrite grains". He also described the ore lenses as being smaller but of higher grade than those of the Colchester Mine.

Gibbs (1967) described the mineralization as striking north 30° east being exposed in three places along a strike length of 70 m. The mineralization has an average width of 0.6 to 1.5 m. Diamond-drill hole #436-11, drilled in 1963, along strike to the northeast of the old workings, was reported by Gibbs (1967) to have intersected 4 m of mineralization grading 3.89 percent Cu. Further drilling to the northeast and northwest intersected only slight mineralization.

Table 13. Summary of diamond drilling carried out by M.J. Boylen Engineering Company and Cerro Mining Company on the McNeilly property (from McArthur, 1971 and Gibbs, 1967)

Hole Number	True Width (ft)	Vertical Depth (ft)	Cu %
71	53.0	+25	0.30
71	14.0	120	0.66
71	23.0	155	0.50
67	83.0	25	0.37
79	30.0	55	0.45
64	23.0	60	1.48
61	14.0	+100	1.15
61	20.0	70	2.55
11	13.0	65	3.89

Note: "Vertical Depth" values are measured from the datum (Colchester Pond). Positive values are above the datum.

Sayeed (1970) described the McNeily mineralization as being hosted by dark-grey, locally talcose chlorite schists that trend north 25° east to north 35° east and dip 70 to 75° southeast.

McArthur (1971) described the mineralization and geology as follows:

> "A greater variety of mineralization occurs in the McNeily Zone than in any of the other prospected areas of the Colchester Mines property. The observed mineral assemblages are pyrrhotite-pyrite-chalcopyrite, banded pyrite-chalcopyrite-sphalerite-pyrrhotite with gold and silver values and chalcopyrite-magnetite. Erratic lenses of moderate chalcopyrite mineralization are known to occur within the McNeily Zone.
>
> The banded massive sulphides appear to be of no economic importance. They include narrow (½") bands (in a siliceous matrix) of pyrite, pyrrhotite, sphalerite and chalcopyrite with gold and silver values......diamond drilling below the stripped areas intersected a wide chlorite zone that correlates well with the surface geology...... drilling results were poor with mainly disseminated pyrite and pyrrhotite antersected."

The reader is referred to McArthur (1971) for diamond-drill sections and detailed plans.

Kean (1984) described the prospect as consisting of chalcopyrite and pyrite occurring in a 30- to 100-m-wide chlorite schist zone. The chlorite-schist zone occurs, at least in places, within a distinctive mafic breccia—agglomerate unit within the pillow lava. Magnetite-rich black chert and small magnetite pods are present in the chlorite schist. The agglomerate and breccia clasts are generally highly variolitic and quartz and/or calcite amygdaloidal. Extensive pyrite is locally present in the matrix and there is locally intense leaching and silicification. A white felsic breccia unit in the vicinity of some of the mineralization may represent either intense silicification or original felsic pyroclastics (Plate 14). Dykes of gabbro, diorite, felsite, and feldspar porphyry are common. Quartz and quartz-chlorite veins are common locally.

Colchester—Main Zone (NTS 12H/9 Cu005) and West Colchester (NTS 12H/9 Cu006)

Location

The Colchester property is located on the east side of Southwest Arm approximately 10 km northeast of King's Point and about 800 m north of McNeily (see Figure 61). Access to the area is provided by a rough gravel road leading from the Harry's Harbour road.

History of Development and Production

Mineralization was discovered at the Colchester site in the 1870s and mining commenced in 1878 (Martin, 1983). The original owner, Southwest Arm Mining Company, optioned the property to the Betts Cove Mining Company in 1878. The mine was named after William Colchester, who was the mine captain and mining entrepeneur Francis Ellershausen's son-in-law (Martin, 1983). By mid-1878, an inclined tramway and a road to Southwest Arm were constructed and three shafts were sunk. The Newfoundland Consolidated Mining Company acquired the Colchester property in December 1880, but left it in 1882 to concentrate on the Little Bay area.

The Geological Survey of Newfoundland reported that the Old Colchester Mine, which started in 1878, included the Middle and New Colchester shafts (Murray and Howley, 1881). The Colchester Mine reopened in 1898, when the Newfoundland Copper Company reopened the Little Bay Mine, and between 1898 and 1901 exported about 273 tonnes of ore from the property.

MacLean (1947) described the development work on the property as consisting of three 'groups' of shafts sunk on three separate ore zones (Douglas *et al.*, 1940). These three 'groups' of shafts were called the Old, Middle and New Colchester shafts (Murray and Howley, 1881) with the New Colchester having been the most extensively developed. Douglas *et al.* (1940) and MacLean (1947) described the New Colchester property as containing three shafts sunk to a depth of 91 m with drifts at 18 m intervals and an adit driven into the hillside across a mineralized shear zone.

Falconbridge Nickel Mines Limited examined the property in 1951 (Bruce, 1951). Chip sampling by Bruce (*op. cit.*) across 2.5 m of the north face of the north pit assayed 1.6 percent Cu (reported by Gibbs, 1967). Bruce also estimated that the five mine dumps on the Colchester property contained about 2000 tonnes grading 1.83 percent Cu (Gibbs, 1967).

M.J. Boylen Engineering obtained the property in 1962, and in 1963 they conducted extensive magnetometer and geological surveys, soil sampling and diamond drilling. The diamond drilling (Table 14) outlined significant copper mineralization in the area of the Colchester 'Main' Zone (Brown, 1967) (see Figure 61). The 'Main' Zone probably included the Middle and New Colchester zones of earlier workers. Four holes were also drilled on the West Zone (Brown, 1967); this zone is probably equivalent to the Old Colchester of earlier workers (see Figure 61). M.J. Boylen Engineering formed Colchester Mines Limited in 1966 and by 1967, 21 diamond drill holes had outlined an estimated ore reserve in the Main Zone of over 1 000 000 tonnes grading 1.3 percent Cu over a strike length of 305 m and to a depth of 183 m (Gibbs, 1967).

Table 14. Diamond-drill results, Colchester Mine (by M.J. Boylen Engineering Company), (from Brown, 1967)

Hole No.	Footage	Length	Cu %	Au oz/ton
436-3	306.0-323.0	17.0	2.58	0.008
436.6	390.0-430.0	40.0	1.73	-----
436.8	395.0-424.2	29.2	1.91	0.01
436.8	494.0-504.0	10.0	1.28	0.01
436.8	734.5-749.2	14.7	1.23	Trace

Gibbs (1967) indicated that chip sampling at the West Zone gave assays of 1.68 percent Cu across 0.3 m in the north face of the open cut and 1.79 percent Cu across 2 m at the collar of the shaft. He also indicated that two diamond-drill holes, drilled near the shaft, intersected narrow mineralized bands assaying less than 1 percent Cu.

In 1969, Cerro Mining Company of Canada conducted a limited geophysical survey on the Colchester property (McArthur, 1971). At that time the road from the base camp, located at the Main Zone, was extended to the Swatridge area. Cerro Mining optioned the property in 1970 and carried out extensive geological, geochemical, topographical and geophysical (magnetometer, SP and IP) surveys. A diamond-drilling program consisting of 26 holes totalling 7588 m was undertaken on the Main Zone (McArthur, 1971) (Table 15). The results indicated that further work was unwarranted.

Local Geology and Mineralization

The Main Zone is hosted by chlorite schist developed within mafic volcanic rocks (Figure 63). These mafic volcanic rocks were described by Douglas *et al.* (1940) as "intensely altered basalt pillow lava and dolerite dykes, which have been intruded by the large Colchester granodiorite—quartz—diorite body about 2000 feet to the east and by smaller granitic bodies near the shafts". Breccia and agglomerate are present locally within the chlorite-schist zone. The chlorite-schist zone varies from strongly to weakly sheared, has a vertical to steep southward dip and trends between N35°E to N65°E (McArthur, 1971). It has a width of 80 m and is weakly mineralized over a distance of over 430 m. Dykes ranging from gabbro to felsite and quartz porphyry are extensive in the area.

The mineralization consists of pyrite and chalcopyrite occurring as disseminations, blebs, stringers, veins and irregular masses in the chlorite schist. Pyrrhotite, magnetite and sulphide-bearing quartz—carbonate veins are also present. Gibbs (1967) described the sulphide mineralization contained within the Main Zone as occurring within nine separate lenses; about half of the estimated tonnage occur in an apparently continuous zone with a strike length of 122 m and a width varying from 1.2 to 18.6 m. The remaining lenses range from 1.2 to 20 m in width. Gibbs (1967) described the lenses as being "roughly parallel, perhaps *en echelon* lenses, dipping south at 80 to 85° and possibly plunging northeast".

McArthur (1971) described the lenses as pinch-and-swell structures that appear to swell in the more chloritic parts of the chlorite-schist zone. He described the chalcopyrite as being quite erratic, forming disseminations, blebs, stringers, veins and local irregular masses. The chalcopyrite is accompanied by variable amounts of, and surrounded by, pyrite mineralization. Faulting has disrupted the lenses and abundant dykes crosscut the zone. Recovery from the lenses would probably be poor (McArthur, 1971).

The West Zone forms a weakly mineralized chlorite-schist zone west of the Main Zone. McArthur (1971) described the schist zone as striking 15° but the strike length, dip and width were not defined.

Table 15. Assay results for diamond drill holes on the Colchester 'Main' Zone by M.J. Boylen Engineering Company and Cerro Mining Company (from McArthur, 1971)

Hole Number	True Width ft	Vertical Depth ft	Cu %
36	37.0	225	0.60
30	23.0	90	2.30
34	14.0	215	0.89
2	13.0	185	1.00
27	-	-	-
40	14.0	+35	0.90
48	80.0	860	1.02
53	30.0	660	0.80
55	7.0	770	0.84
59	8.0	415	1.33
3	18.0	160	2.60
16	15.0	+40	1.13
16	17.0	105	1.70
16	69.0	370	0.95
8	14.0	275	1.81
8	9.0	350	0.95
8	38.0	520	0.76
72	21.0	335	0.77
72	9.0	382	1.01
72	108.0	378	0.42
4	12.0	217	0.84
25	28.0	290	0.70
31	82.0	440	0.80
69	12.0	355	1.00
50	85.0	660	0.93
24	25.0	135	0.75
5	17.0	192	0.93
5	33.0	250	0.50
21	95.0	115	1.20
6	95.0	235	0.97
18	11.0	520	0.75
18	26.0	725	1.05
49	110.0	500	0.80
73	50.0	590	0.80
73	28.0	690	0.90
22	23.0	280	0.90
75	38.0	320	0.43
75	30.0	455	0.68
62	24.0	525	0.88
62	16.0	655	1.00
62	50.0	705	0.56
35	43.0	205	1.06
35	32.0	480	0.57
33	12.0	115	1.20
37	24.0	130	1.30
37	30.0	335	1.06
38	26.0	450	1.13
38	85.0	310	0.71
45	115.0	725	0.76
41	103.0	335	1.05
39	55.0	375	0.66
39	55.0	440	0.79
56	11.0	600	1.00
44	13.0	340	1.28
42	3.0	485	1.32
74	20.0	65	1.22
52	100.0	450	0.84
70	25.0	375	0.62
51	40.0	225	1.44
51	65.0	480	1.04
54	18.0	515	0.57
54	24.0	575	0.54
57	42.0	640	0.36
57	35.0	880	0.50

Note: "Vertical Depth" values are measured relative to the datum (Colchester Pond) with positive values above the datum.

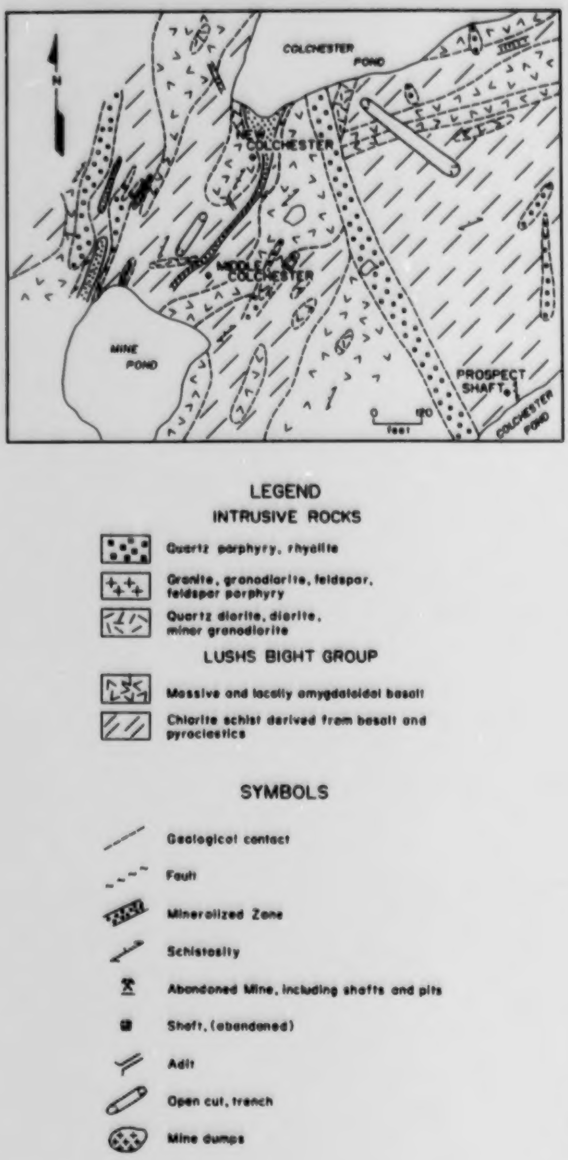

N
COLCHESTER POND
NEW COLCHESTER
MIDDLE COLCHESTER
MINE POND
PROSPECT SHAFT
COLCHESTER POND
0
100
feet
LEGEND
INTRUSIVE ROCKS
Quartz porphyry, rhyolite
Granite, granodiorite, feldspar, feldspar porphyry
Quartz diorite, diorite, minor granodiorite
LUSHS BIGHT GROUP
Massive and locally amygdaloidal basalt
Chlorite schist derived from basalt and pyroclastics
SYMBOLS
Geological contact
Fault
Mineralized Zone
Schistosity
Abandoned Mine, including shafts and pits
Shaft, (abandoned)
Adit
Open cut, trench
Mine dumps

Figure 63. *Geology map of the Colchester area (see McArthur, 1971).*

Old English (NTS 12H/9 Cu007)

Location

The Old English Mine showing is situated about 200 m east of the southeast shore of Southwest Arm, Green Bay, north of Colchester. The old mine site can be reached by a rough road that leads northward from the Colchester area.

History of Development and Production

MacLean (1947) reported that the prospect, known variously as the Location, Pill's and Old English, was first developed in 1878 and was mined intermittently over a five-year period. During that time, three shafts were sunk and some trenches were dug on a 3-m-wide shear zone. Douglas *et al.* (1940) indicated a 67-m-long adit was driven into the hillside and connected with one of the shafts. They also reported that underground workings consisted of 122 m of westward drifting and 37 m of eastward drifting. There was a 240-m (800-foot) double-track tramway that ran from one of the mine's shafts down to a wharf on Southwest Arm. The mine was operated by two dozen miners who worked under mine captain William Pill of England (Martin, 1983).

> "The Old English Mine produced a small amount of ore of unknown tonnage in 1879 and 1880. Before the Consolidated Mining Company abandoned the mine in 1882, another 490 tons left the 'Southwest Arm mines'; those being the Old English and the adjacent Colchester mines" (Martin, 1983).

Falconbridge Nickel Mines Limited examined the Colchester area in 1957 (Brown, 1963). M.J. Boylen Engineering Company obtained exploration rights to the various Colchester Fee Simple Grant properties in 1962. Between 1963 and 1964, M.J. Boylen conducted geological mapping, magnetic and geochemical surveys and drilled one diamond-drill hole. Colchester Mines Limited drilled eight holes in 1966 and outlined a mineralized zone having an average grade greater than 1 percent Cu (Brown and Marchant, 1966). Gibbs (1967) reported assay results up to 5.22 percent Cu over a zone extending 1.3 m from the main shaft.

Cerro Mining Company of Canada Limited optioned the Colchester Mine properties from M.J. Boylen Engineering Company in 1970 (McArthur, 1971). The company trenched and stripped a magnetic anomaly delineated by M.J. Boylen. This trenching exposed widespread, weak to moderate chalcopyrite mineralization. Cerro drilled four holes and intersected a 70-m-wide zone of weak copper mineralization (Table 16), but dropped the option in 1970. Colchester Mines Limited drilled three holes totalling 663 m in 1972. They intersected minor copper mineralization, the best grading 2.48 percent over 1.5 m.

Local Geology and Mineralization

The mineralization occurs in chlorite schist derived from mafic volcanic rocks along the western contact of the Colchester Pluton. The mineralization was described by MacLean (1940) as occurring in a 3-m-wide shear zone, which was traced for 91 m. MacLean (1947) described the sulphide mineralization as consisting of pyrite, chalcopyrite, marcasite and wurtzite and occurring as lenses within the shear zone.

Table 16. Results of diamond drill holes by M.J. Boylen Engineering Company and Cerro Mining Company on the Old English property (from McArthur, 1971)

Hole Number	True Width ft	Vertical Depth ft	Cu %
17	7.0	228	0.45
17	7.0	310	0.68
19	24.0	133	0.32
19	20.0	160	0.63
19	8.0	220	0.94
23	12.0	82	0.31
23	42.0	130	0.62
76	30.0	153	0.79
76	65.0	240	0.47
78	99.0	320	0.77
26	9.0	95	1.67
83	155.0	290	0.52
32	12.0	85	1.35

Note: "Vertical Depth" values are measured from the datum (Colchester Pond).

Sayeed (1970) described three mineralized zones in the vicinity of the Old English Mine. The first, consisting of small veins and stringers of pyrite and chalcopyrite, is hosted by a 3-m-wide chlorite-schist zone. The schist strikes 035°, dips 75° southeast and is exposed in a pit 1500 m north of the Colchester Main Zone. The second zone is a mineralized quartz-chlorite schist that is cut by mineralized quartz veins. The schist trends north, dips 50° east and is located 230 m northeast of the first pit. The third mineralized zone is exposed in a pit 685 m northeast of the second pit. Here, chalcopyrite and pyrite form thin stringers up to 2.5 cm long in sheared quartz-chlorite schists. The shear zone trends 030° and is vertical.

Swatridge (NTS 12H/9 Cu008)

Location

This prospect is located on the eastern side of Southwest Arm, Green Bay near the west end of the Saunders Brook fault. It is readily accessible by boat.

History of Development and Production

The Swatridge was the oldest and most northeasterly of five copper mines along the east coast of Southwest Arm. Two prospect shafts were sunk during the fall of 1876 by a St. John's firm known as the Southwest Arm Mining Company (Martin, 1983). Numerous trenches and pits were also reported in this area. The mining venture closed in the spring of 1877 after only a few tonnes of ore were mined. Both Douglas *et al*. (1940) and Maclean (1947) briefly examined the Swatridge property and determined the mineralization to be hosted by chlorite schist.

The Swatridge Fee Simple Grant was included in the option obtained by M.J. Boylen Engineering Company in 1962. Mapping and a magnetometer survey were carried out in 1963 and 1964 (Brown, 1963; Brown and Marchant, 1964), but the mineralized schist at the old mine site produced the only significant magnetic anomaly. Cerro Mining Company of Canada optioned the property from M.J. Boylen and carried out a self-potential (SP) survey of the Swatridge property in 1969 (McArthur, 1971). The survey outlined a 350-m-long anomaly associated with one of the mineralized zones. Cerro dropped its option in 1970. The Fee Simple Grant reverted to the Crown in 1987.

Local Geology and Mineralization

The prospect is located near the Saunders Cove fault and occurs within chlorite schist developed in mafic volcanic rocks. Basaltic pillow lava and extensive diabase and gabbro underlie the surrounding area. The chlorite schist trends 055° and dips 70° north; however, the highly mineralized schist trends 070° and dips 65° north. The schist is approximately 60 cm wide and contains mineralized bands of disseminated sulphides that are up to 5 cm thick. The mineralization consists of disseminated chalcopyrite and pyrite along with minor magnetite and sphalerite.

Sterling Mine (NTS 12H/9 Cu009)

Location

The Sterling Mine is located 180 m north of Sterling Pond approximately 1.5 km north-northwest of the community of Springdale. It can be reached by footpaths and tractor roads from the old BRINEX base camp and the Springdale area.

History of Development and Production

Thomas Peyton discovered the prospect around 1879 and along with Dr. William Stirling and two other individuals obtained a Fee Simple Grant for the property, at which time it was called the 'Halls Bay' mine (Martin, 1983). However, it was nicknamed the 'Whim Shaft mine' because of the horse-driven whim or winch used at the site. During the period 1880 to 1882 two mine shafts and four test-pits were sunk on the prospect by the Betts Cove Mining Company. Approximately 240 tonnes of copper ore was produced (Plate 34). It was later renamed the Sterling Mine when Dr. Stirling's opera-singer daughter, Georgina "Toulinquet" Sterling, became a part-owner in 1916 (Martin, 1983).

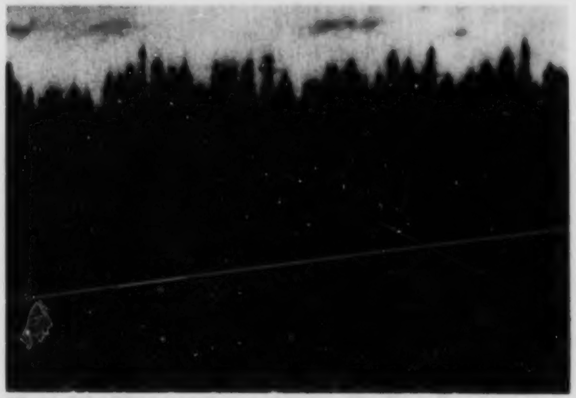


Plate 34. *Waste and ore dumps, Sterling Prospect (ca. 1983).*

In 1952, Falconbridge Nickel Mines Limited explored the property but subsequently dropped their option. BRINEX acquired exploration rights to the Fee Simple Grant in the early 1960s. A geochemical soil survey carried out in 1964 indicated several copper anomalies. Subsequently, in 1968, Sander Geophysics Limited (Sander, 1968) flew a combined helicopter-borne electromagnetic (EM) and magnetic survey over the property, which led to the drilling of 51 holes with a total footage of 9545 m on the Sterling and the nearby Twin Pond showings.

McArthur (1973) studied the geology of the Sterling Mine as part of a M.Sc. thesis at Memorial University of Newfoundland. His A-zone corresponds to the old Sterling Mine and his B-zone to the (Lower) Twin Pond prospect.

Local Geology and Mineralization

The Sterling Mine prospect (A-zone of McArthur, 1973) is hosted by a zone of chloritic metabasalt developed within epidotized basalt (Figure 64). Tuffaceous schists, siliceous tuffaceous schists, volcanic breccia, isolated pillow breccia and white-weathering, green dacitic pyroclastic rocks also occur in the stratigraphic sequence hosting the mineralization. The sulphides occur as

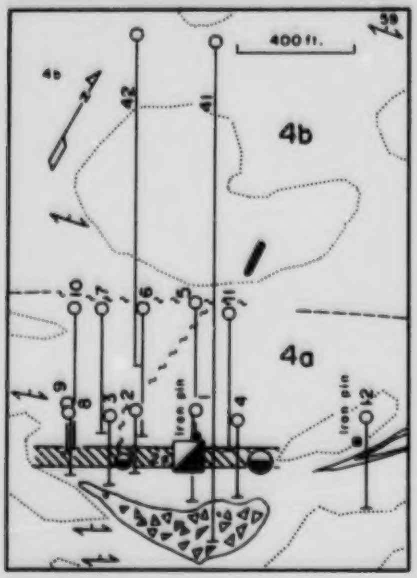


Figure 64. *Location and geological setting of the Sterling prospect (see McArthur, 1973).*

LEGEND

JURASSIC OR EARLY CRETACEOUS (?)

7	*Lamprophyre*

ORDOVICIAN AND YOUNGER

MAFIC INTRUSIVE ROCKS

6a	*Feldspar porphyry*
6b	*Medium-grained gabbro and diorite*
6c	*Fine-grained diorite and diabase*
5	*Rhyolite, felsite*

EARLY ORDOVICIAN

LUSHS BIGHT GROUP

4a	*Epidote basalt*
4b	*Isolated pillow basalt*
3	*Volcanic breccia*
2a	*Chloritic basalt*
2b	*Schistose chloritic basalt*
1a	*Tuffaceous schists*
1b	*Siliceous tuffaceous schists*
▨	MINERALIZED ZONE: *pyrite-chalcopyrite*

SYMBOLS

Outcrop
Geological contact
Limit of geological mapping
First fabric (cleavage and schistosity) S_1
Second fabric (kink bands and crenulations) S_2
Drag-fold
Fault
Dyke
Mine dump
Shaft
Test pit or trench
Diamond-drill hole
Pond
Marsh
Trail
Topographic contour
Elevation, feet above sea level
Overburden

semi-massive to massive lenses and pods, stringer stockwork and disseminations of pyrite, chalcopyrite with minor pyrrhotite, sphalerite and marcasite within a chlorite, quartz and calcite gangue (McArthur, 1973). The mineralized zone strikes 060° and dips 60 to 70° northwest, has a strike length of 120 m and appears to pinch out on both ends. The mineralization has a projected vertical depth of about 210 m. High-grade diamond-drill intersections of chalcopyrite assayed 5.5 percent Cu over 4.4 m, with one intersection running 1.7 percent Cu over 13.7 m (McArthur, 1973). Figures 65 and 66 are typical drill sections for the Sterling Mine (or A-zone).

The schist zone is described by McArthur (1973) as steeply dipping and conformable with both structure and stratigraphy. However, within the zone, high-grade sulphide stringers locally exhibit crosscutting relationships. All primary sulphide textures have been destroyed by recrystallization and remobilization due to deformation. Pyrite, the dominant sulphide, is medium to coarse grained and granoblastic to euhedral. Pyrite crystals commonly exhibit broken and crushed corners and fractures produced by brittle deformation. Large angular fragments of massive sulphides consisting mainly of pyrite with interstitial chalcopyrite can be found in the dumps.

Drillhole intersections of high-grade chalcopyrite (McArthur, 1973) consist of massive to semi-massive chalcopyrite having lesser amounts of pyrite usually asinclusions within the chalcopyrite. Lower grade intersections consist of chalcopyrite occurring as veins interstitial to and cutting pyrite grains. The chalcopyrite

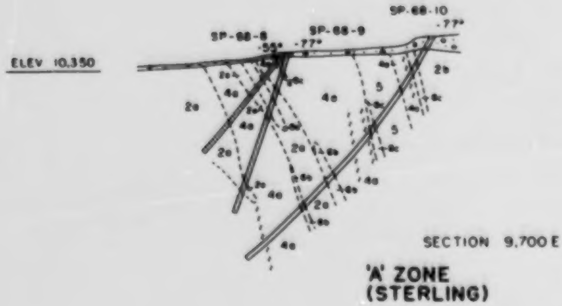


Figure 65. *Section 9 700 E showing diamond-drill holes SP-68-8, 9 and 10, Sterling prospect (see McArthur, 1973).*

consists typically of fine-grained, anhedral crystals (McArthur, *op. cit.*). Minor fine-grained euhedral sphalerite occurs within chalcopyrite and as borders to and fracture fillings within pyrite. Rare marcasite was also reported by McArthur (1973).

Twin Pond Prospect (12H/9 Cu/010)

Location

The Twin Pond prospect (Sterling B-zone, McArthur, 1973) is located immediately north of Lower Twin Pond (Figure 67), about 1.5 km north of Springdale and approximately 800 m east-northeast of the Sterling Mine.

History of Development

First exploration activity consisted of a test-pit that was probably developed during the Betts Cove Mining Company's development of the nearby Sterling Mine. The area was examined by Falconbridge Nickel Mines in 1952. BRINEX leased the Sterling Fee Simple Grant in the early 1960s (see Sterling prospect for description of BRINEX activities). McArthur (1973) included the Twin Pond prospect in his M.Sc. thesis on the geology of the Sterling area.

Local Geology and Mineralization

McArthur (1973) described the Twin Pond (or Sterling B-zone) as being hosted by siliceous tuffaceous schists and minor chloritic metabasalt. The mineralization occurs in

LEGEND

JURASSIC OR EARLY CRETACEOUS (?)

7	*Lamprophyre*

ORDOVICIAN AND YOUNGER

MAFIC INTRUSIVE ROCKS

6a	*Feldspar porphyry*
6b	*Medium-grained gabbro and diorite*
6c	*Fine-grained diorite and diabase*
5	*Rhyolite, felsite*

EARLY ORDOVICIAN

LUSHS BIGHT GROUP

4a	*Epidote basalt*
4b	*Isolated pillow basalt*
3	*Volcanic breccia*
2a	*Chloritic basalt*
2b	*Schistose chloritic basalt*
1a	*Tuffaceous schists*
1b	*Siliceous tuffaceous schists*
▨	MINERALIZED ZONE: *pyrite-chalcopyrite*

SYMBOLS

Outcrop
Geological contact
Limit of geological mapping
First fabric (cleavage and schistosity) S_1
Second fabric (kink bands and crenulations) S_2
Drag-fold
Fault
Dyke
Mine dump
Shaft
Test pit or trench
Diamond-drill hole
Pond
Marsh
Trail
Topographic contour
Elevation, feet above sea level
Overburden

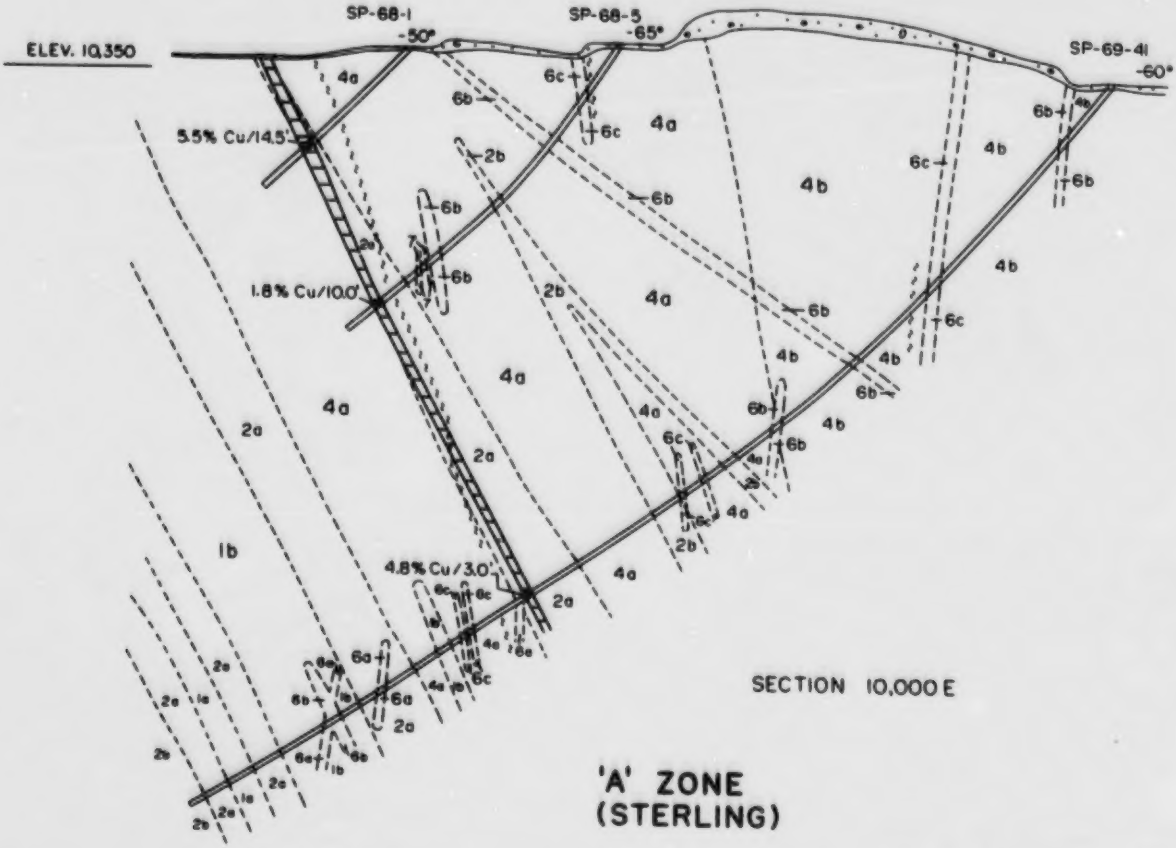


Figure 66. *Section 10 000 E showing diamond-drill holes SP-68-1, 5 and SP-60-41, Sterling prospect (see McArthur, 1973).*

several lensoidal zones containing lenses, pods, stringers and disseminations. The mineralized zone strikes 060 to 070° and dips 60 to 70° northwest, parallel to the stratigraphy and main regional foliation. The zone has a strike length of > 430 m and a vertical extension greater than 275 m.

Pyrite is the predominant sulphide and chalcopyrite is generally present in trace amounts, locally up to 1 percent (McArthur, 1973). Sphalerite has not been reported from this prospect. Pyrrhotite occurs both as fine-grained disseminations and as massive to semi-massive veins up to a few centimetres thick. Pyrrhotite also occurs as grains within and interstitial to coarse pyrite grains. Intersections in drill core include 0.57 percent Cu over 12 m, 0.8 percent Cu over 30 m, 1.3 percent Cu over 5.8 m and 0.5 percent Cu over 29 m (Figures 68 and 69).

Sullivan Pond (NTS 12H/9 Cu011)

Location

The Sullivan Pond prospect is located about 1 km north of the Springdale hospital. It is located on the north side of Sullivan Pond within 200 m of its eastern end and can be reached by road from Springdale.

History of Development and Production

The prospect was discovered by Thomas Peyton in 1875. Peyton, Dr. William Stirling and two others obtained a Fee Simple Grant for the property and leased the property to the Betts Cove Mining Company in 1878 (Martin, 1983). An unspecified amount of ore was shipped to the Little Bay smelter. The operation closed late in 1879 when mining moved to the nearby Sterling property (Marten, 1983). There are at least two shafts on the prospect.

BRINEX first examined the old mine site in 1955 but it was not until 1965 that an extensive exploration program was initiated. The program involved line cutting, geological mapping, trenching, geochemistry (soil sampling) and geophysics. The geophysics, consisting of ground magnetic, self-potential (SP), electromagnetic (EM)

LEGEND (Figure 66)

JURASSIC OR EARLY CRETACEOUS (?)

7	*Lamprophyre*

ORDOVICIAN AND YOUNGER

MAFIC INTRUSIVE ROCKS

6a	*Feldspar porphyry*
6b	*Medium-grained gabbro and diorite*
6c	*Fine-grained diorite and diabase*
5	*Rhyolite, felsite*

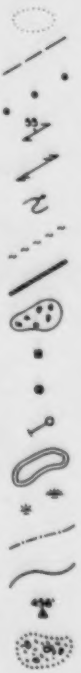
EARLY ORDOVICIAN

LUSHS BIGHT GROUP

4a	*Epidote basalt*
4b	*Isolated pillow basalt*
3	*Volcanic breccia*
2a	*Chloritic basalt*
2b	*Schistose chloritic basalt*
1a	*Tuffaceous schists*
1b	*Siliceous tuffaceous schists*
▨	MINERALIZED ZONE: *pyrite-chalcopyrite*

SYMBOLS

Outcrop
Geological contact
Limit of geological mapping
First fabric (cleavage and schistosity) S_1
Second fabric (kink bands and crenulations) S_2
Drag-fold
Fault
Dyke
Mine dump
Shaft
Test pit or trench
Diamond-drill hole
Pond
Marsh
Trail
Topographic contour
Elevation, feet above sea level
Overburden



and induced potential (IP) surveys, outlined four anomalous zones. A M.Sc. thesis at the Royal School of Mines (Morris, 1966) was conducted on the Sullivan Pond prospect and surrounding area. Subsequently, BRINEX drilled eleven holes in 1967 and five in 1969 but failed to intersect economic mineralization.

Local Geology and Mineralization

The mineralization is hosted by chlorite schist developed in mafic volcanic rocks. The chlorite schist trends 70° and is vertical. Some small isolated fragments of red chert, possibly representing original interpillow material, are present. Minor diabase dykes are also present. Pyrite and minor chalcopyrite occur as disseminations, pods and crosscutting veinlets and are generally accompanied by extensive quartz veining.

Morris (1966) described the mineralization as consisting of fine-grained pyrite and disseminated chalcopyrite in a gangue of quartz and calcite. The massive ore contained fine-grained pyrite, with disseminated chalcopyrite, interstitial quartz and minor calcite and chlorite. He reported that in polished section the pyrite is broken and infilled with chalcopyrite and gangue. Exsolution blebs of chalcopyrite and small rounded grains of illmenite occur in some of the pyrite. Minor crosscutting veinlets of chalcopyrite, sphalerite and quartz are also present. Minor sphalerite also occurs interstitial to the pyrite and as late-stage veinlets.

Lady Pond Mine (NTS 12H/9 Cu013)

Location

The Lady Pond Mine is located at the northeastern end of Lady Pond, approximately 1.5 km south of Davis Pond and can only be reached on foot.

History of Development and Production

Howley referred to the mine in his geological reports for 1892, 1898 and 1899. At the time, the property was being worked by the Little Bay Mining Company. The ore, obtained from seven shafts (Plate 35), which were sunk to a depth of about 35 m, was crushed and concentrated on site by jigs before being shipped. Production from the mine was included with the Little Bay Mine production data; therefore, the amount of ore produced is not known. MacLean (1947), in his examination of the mineral deposits of the Little Bay area, briefly studied the Lady Pond Mine. He described the shafts as being aligned north 85° west over a distance of about 300 m. All of the shafts were reported to have intersected mineralization.

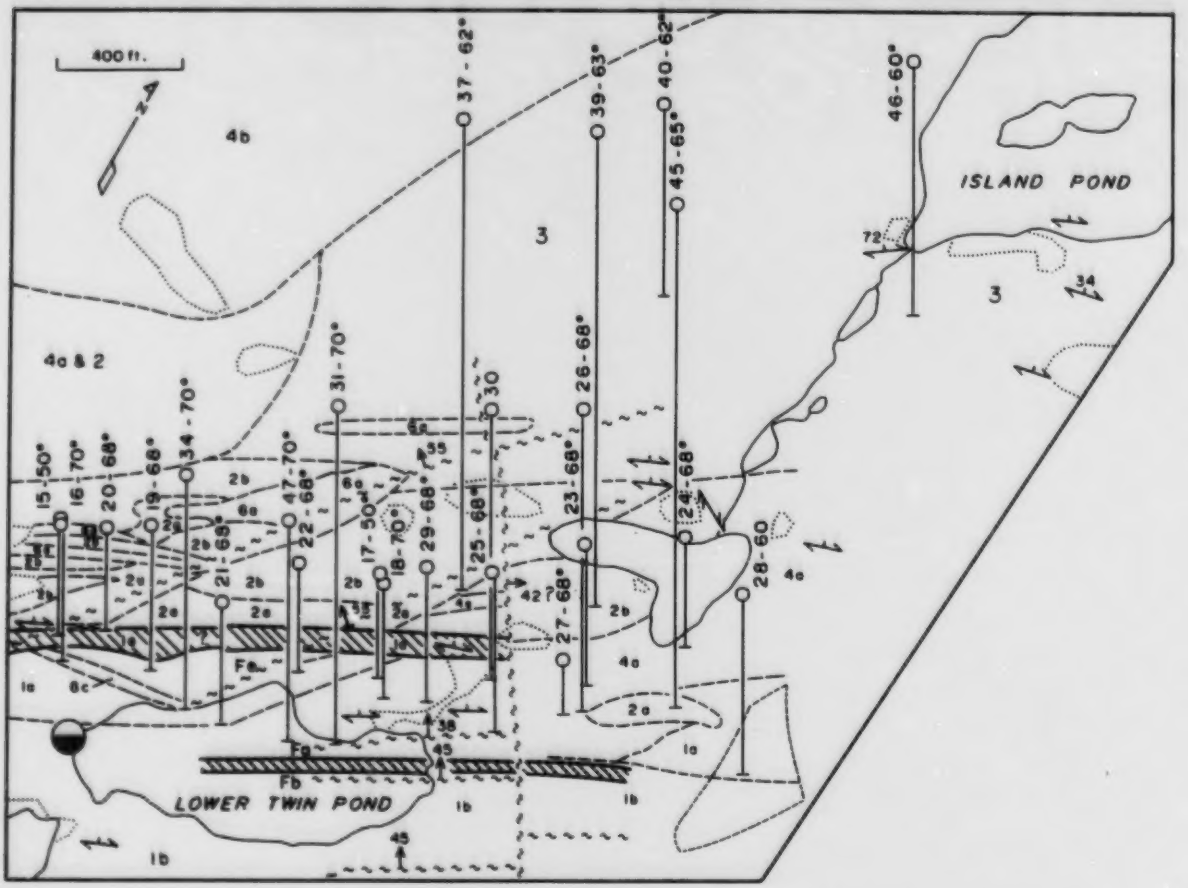


Figure 67. *Location and geology of the (Lower) Twin Pond prospect (see McArthur, 1973).*

The property was optioned by Falconbridge Nickel Mines Limited from 1951 to 1954, and 10 holes were drilled in the vicinity of the old mine. BRINEX first expressed interest in the property in 1957 (Hansuld, 1957), however it was optioned by Atlantic Coast Copper in 1960, who conducted magnetometer and EM surveys, geological mapping, trenching and diamond drilling consisting of 4 holes in 1961 (MODS File NTS 12H/9 Cu013). The company drilled a further 4 holes in 1962, and followed up with an IP survey in 1963. In 1964, an additional 8 holes were drilled. Low-grade mineralization was intersected in most holes.

BRINEX conducted exploration to the immediate west of the property in 1964 (Bedford, 1964). This work consisted of line cutting, geological mapping, geophysics, geochemistry and 16 diamond-drill holes. Seven of the holes were drilled around the western edge of Lady Pond and the remaining nine holes were drilled 400 m to the west. Assays from the drill core ranged from 0.62 to 2.59 percent Cu with traces of Au and Ag reported from some holes. Detailed mapping was carried out by BRINEX in 1966 (Jaworski, 1966).

Gale (1969) included the Lady Pond prospect in a M.Sc. study of the primary dispersion patterns of Cu, Zn, Ni, Co, Mn and Na around selected sulphide deposits of the Springdale Peninsula. His study was mainly restricted to an examination of drill core from the southwest end of Lady Pond.

The Fee Simple Grant (Volume A, Folio 85), owned by John Wilson, reverted to the Crown in 1982.

Local Geology and Mineralization

MacLean (1947; see also Douglas *et al.*, 1940) described the mineralization as being hosted by basaltic pillow lava, basalt porphyries and dolerite dykes that have been intensely altered to chlorite, clinozosite and quartz. The mineralization, which appears to occur as discrete lenses, is contained in a strongly schistose and brecciated

LEGEND (Figure 67)

JURASSIC OR EARLY CRETACEOUS (?)

7	*Lamprophyre*

ORDOVICIAN AND YOUNGER

MAFIC INTRUSIVE ROCKS

6a	*Feldspar porphyry*
6b	*Medium-grained gabbro and diorite*
6c	*Fine-grained diorite and diabase*
5	*Rhyolite, felsite*

EARLY ORDOVICIAN

LUSHS BIGHT GROUP

4a	*Epidote basalt*
4b	*Isolated pillow basalt*
3	*Volcanic breccia*
2a	*Chloritic basalt*
2b	*Schistose chloritic basalt*
1a	*Tuffaceous schists*
1b	*Siliceous tuffaceous schists*
▨	MINERALIZED ZONE: *pyrite-chalcopyrite*

SYMBOLS

Outcrop

Geological contact

Limit of geological mapping

First fabric (cleavage and schistosity) S_1

Second fabric (kink bands and crenulations) S_2

Drag-fold

Fault

Dyke

Mine dump

Shaft

Test pit or trench

Diamond-drill hole

Pond

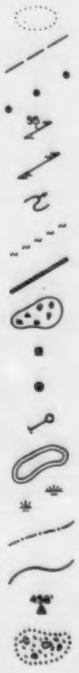
Marsh

Trail

Topographic contour

Elevation, feet above sea level

Overburden



zone. MacLean (1947) noted that the apparent N 85°W trend of the mineralized zone crosses the regional northeast trend of the host rocks. However, this northwest trend was deduced from the alignment of a series of shafts and not the trace of the chlorite schist zones. Northwest-trending dykes are extensive in this area. The following description of the mineralogy is taken from Douglas *et al.* (1940).

> "The metallic minerals, in order of introduction, are magnetite, pyrite, chalcopyrite, pyrrhotite, bornite, and wurtzite. The non-metallic gangue is quartz. There is some rare supergene alteration along fractures in the chalcopyrite and bornite to covellite. Magnetite is the earliest metallic mineral and is present in large masses in these deposits; some of the ore specimens are three-quarters magnetite, one quarter interstitial quartz, and a little chalcopyrite and bornite of late introduction. The pyrite is veined along fractures by quartz and chalcopyrite. Bornite is present in considerable amount as a primary mineral contemporaneous with and also replacing chalcopyrite along joints and crystal cleavages; some of the large bornite grains have parallel residual sheets of chalcopyrite. The pyrrhotite is both contemporaneous with and later than the chalcopyrite. The wurtzite is a late primary mineral and was seen in a small amount in one specimen as distinctly anisotropic grains in fractures in the quartz and replacing pyrite and chalcopyrite."

Gale (1969) described the mineralization present in diamond-drill core obtained from the southwest end of Lady Pond as consisting of chalcopyrite and pyrrhotite veinlets that are up to 2.5 cm in width. Pyrite occurs as massive bands up to 7.5 cm thick and as veins up to 2.5 cm wide scattered throughout the country rocks. The massive pyrite contains small irregular chalcopyrite veinlets and bornite; wurtzite and magnetite are also present. Chlorite and quartz form the principal gangue minerals. Gale (1969) described the host rocks as fine-grained, dark-green tuffaceous and fragmental rocks, andesitic lavas and dioritic dykes. All have been variably deformed and altered to chlorite and epidote. Fresh porphyritic feldspar and amphibole dykes cut the country rocks.

Gale (1969) described the dispersion pattern for Cu, Zn, Mn and Na for samples obtained from a diamond-drill hole at the southwest end of Lady Pond as the most irregular obtained from his study. He attributed this to either the action of mineralizing fluids or the original heterogeneous chemistry of the host rocks. The Na content appears to vary inversely with the degree of chloritization.

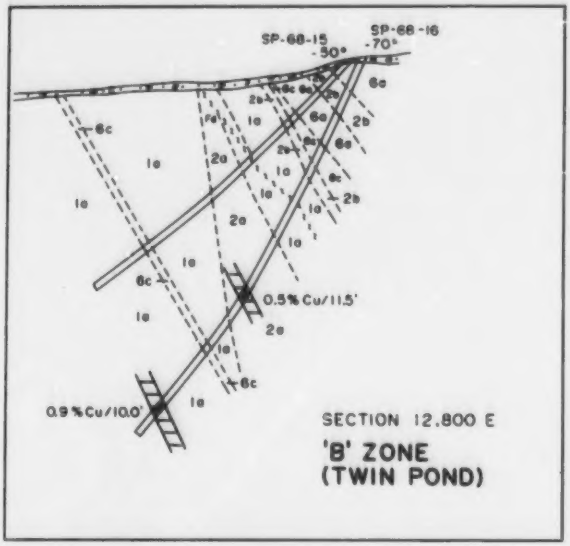


Figure 68. *Section 12 800 E showing DDHs SP-68-15 and 16, Twin Pond prospect (see McArthur, 1973).*

There is also some suggestion that the Cu content is inversely related to the Na content. He suggested that this may represent a possible relationship between Cu content and the degree of chloritization.

The prospect is in variolitic and quartz amygdaloidal pillow lava and breccia with extensive diabase dykes and is located approximately 200 m above the contact with an area of sheeted dykes to the south (Kean, 1983). In some areas near the prospect, diabase dykes constitute 60 percent of the exposure. Intensely silicified rocks and possibly minor felsic tuff are also present in the mineralized zone. Shearing is locally well developed. Boninitic dykes and variolitic interdyke lava occur in the fault block to the north.

Very little mineralization is exposed on the surface, except for thin interpillow lenses of magnetite and magnetite-rich black chert, and disseminated pyrite in chloritic mafic volcanic rocks. Samples from the dumps vary from massive magnetite with minor quartz and chalcopyrite to stringers and disseminations of pyrite, chalcopyrite and pyrrhotite in chlorite schist. There are no massive sulphides exposed either at the old mine or in samples from the dump. Quartz veining is common.

Timber Pond (NTS 12H/9 Zn002 and Au003)

Location

The Timber Pond massive sulphide and gold showings are located approximately 5 km northwest of Springdale.

LEGEND

JURASSIC OR EARLY CRETACEOUS (?)

7	*Lamprophyre*

ORDOVICIAN AND YOUNGER

MAFIC INTRUSIVE ROCKS

6a	*Feldspar porphyry*
6b	*Medium-grained gabbro and diorite*
6c	*Fine-grained diorite and diabase*
5	*Rhyolite, felsite*

EARLY ORDOVICIAN

LUSHS BIGHT GROUP

4a	*Epidote basalt*
4b	*Isolated pillow basalt*
3	*Volcanic breccia*
2a	*Chloritic basalt*
2b	*Schistose chloritic basalt*
1a	*Tuffaceous schists*
1b	*Siliceous tuffaceous schists*
▨	MINERALIZED ZONE: *pyrite-chalcopyrite*

SYMBOLS

Outcrop

Geological contact

Limit of geological mapping

First fabric (cleavage and schistosity) S_1

Second fabric (kink bands and crenulations) S_2

Drag-fold

Fault

Dyke

Mine dump

Shaft

Test pit or trench

Diamond-drill hole

Pond

Marsh

Trail

Topographic contour

Elevation, feet above sea level

Overburden

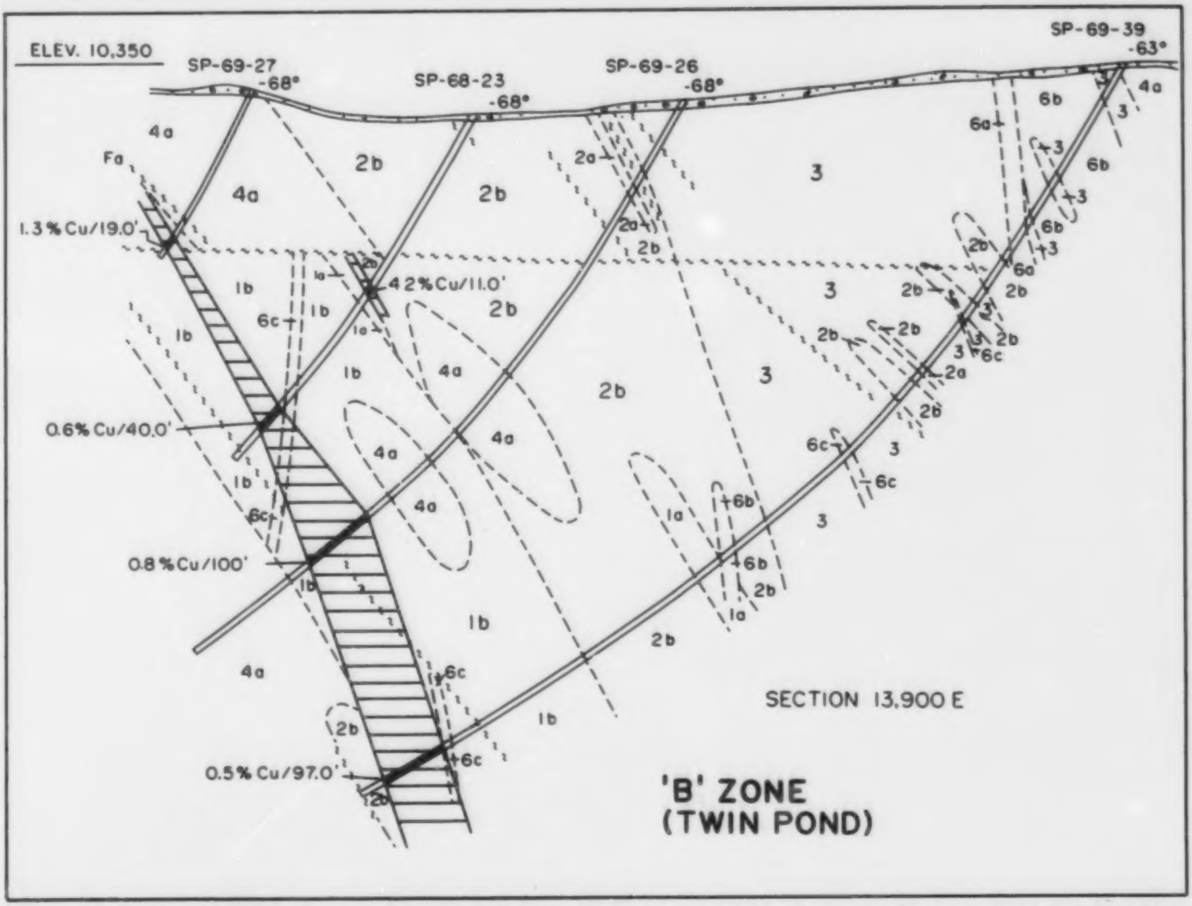

ELEV. 10,350
SP-69-27
-68°
SP-68-23
-68°
SP-69-26
-68°
SP-69-39
-63°
Fa
1.3 % Cu/19.0'
4 2 % Cu/11.0'
0.6% Cu/40.0'
0.8 % Cu/100'
0.5 % Cu/97.0'
4a
2b
3
1b
6c
1a
2a
6a
6b
SECTION 13,900 E
'B' ZONE
(TWIN POND)

Figure 69. *Section 13 900 E showing diamond-drill holes SP-68-23 and SP-69-26, 27 and 39, Twin Pond (see McArthur, 1973).*

Plate 35. *Lady Pond prospect with dumps and old shafts (ca. 1983).*

The area can be reached by forest access roads from the Little Bay highway.

History of Development

The Timber Pond massive sulphide showing was discovered in the spring of 1986 by Noranda during the course of exploration activity on the nearby Timber Pond gold showing located 225 m to the east. The gold mineralization was discovered in the fall of 1985 by Noranda as part of a regional till and stream-sediment geochemical survey (Andrews and Walker, 1990). A panned concentrate of stream sediment from a stream flowing from Timber Pond had a highly anomalous gold value of 6400 ppb. Trenching (Figure 70), diamond drilling and extensive geochemical and geophysical surveys have been carried out in the area.

Local Geology and Mineralization

The following description of the massive sulphide and gold mineralization is taken from Andrews and Walker (1990).

LEGEND (Figure 69)

JURASSIC OR EARLY CRETACEOUS (?)

7	*Lamprophyre*

ORDOVICIAN AND YOUNGER

	MAFIC INTRUSIVE ROCKS
6a	*Feldspar porphyry*
6b	*Medium-grained gabbro and diorite*
6c	*Fine-grained diorite and diabase*
5	*Rhyolite, felsite*

EARLY ORDOVICIAN

	LUSHS BIGHT GROUP
4a	*Epidote basalt*
4b	*Isolated pillow basalt*
3	*Volcanic breccia*
2a	*Chloritic basalt*
2b	*Schistose chloritic basalt*
1a	*Tuffaceous schists*
1b	*Siliceous tuffaceous schists*
▨	MINERALIZED ZONE: *pyrite-chalcopyrite*

SYMBOLS

Outcrop

Geological contact

Limit of geological mapping

First fabric (cleavage and schistosity) S_1

Second fabric (kink bands and crenulations) S_2

Drag-fold

Fault

Dyke

Mine dump

Shaft

Test pit or trench

Diamond-drill hole

Pond

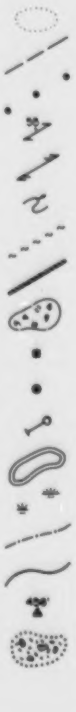
Marsh

Trail

Topographic contour

Elevation, feet above sea level

Overburden



> "It was trenched following the discovery of gossan and massive sulphides in bedrock. A unit of massive sulphides 4 m thick and 8 m long was exposed.......
>
> Bedding laminations in the sulphides strike E-W and dip steeply to the north, conforming to the penetrative cleavage in the area. Intense chloritization, pyritization and stringer pyrite mineralization characterize the country rock to the north. It is interpreted to represent footwall alteration to the deposit, which implies the deposit and surrounding strata are overturned. The southern limit of the massive sulphide was not exposed by trenching.
>
> The mineralogy is predominantly pyrite, but pyrrhotite, thin laminations of sphalerite and lenses of chalcopyrite are observed. Recrystallization of the sulphides has led to the formation of chalcopyrite "porphyroblasts", 2-4 mm in diameter, in the pyrite. Sphalerite is more common in the southern part of the showing. Assay values obtained from 1 m channel sampling across the sulphides are up to 0.75 g/t Au, 6.5 g/t Ag, 1.4% Cu and 1.05% Zn and 2.0m of 1.0% Cu and 2.42% Zn. The massive sulphides have been traced by diamond drilling down dip and along strike to the west. A number of strong geophysical and geochemical trends indicate the potential for further base metal mineralization along strike to the east and west and the showing itself remains open in all directions.
>
> The gold mineralization is associated with a sheared and brecciated interflow sediment that consists of basaltic ash in a cherty matrix...... . The host rock contains up to 15% disseminated pyrite. The sediment varies in thickness from 1-2 m and is exposed over 15 m of strike length. It parallels a strong E-W cleavage and locally thickens in the hinge of an open, 2 m wide, steeply NW-plunging fold. The sediment occurs within a thin unit of basaltic tuff interbedded with massive and pillow basalt flows. Analysis of chip samples across the zone gives values of 5.1 g/t Au, 102.3 g/t Ag, 0.07% Cu, 0.38% Pb and 0.56% Zn over 1.0 m."

The Timber Pond massive sulphide and gold showings are on strike with each other, and occur at a stratigraphic level that appears to record the waning stages of volcanism and the onset of clastic and chemical sedimentation at the uppermost part of the Lushs Bight Group. The showings may be genetically related, with the gold showing

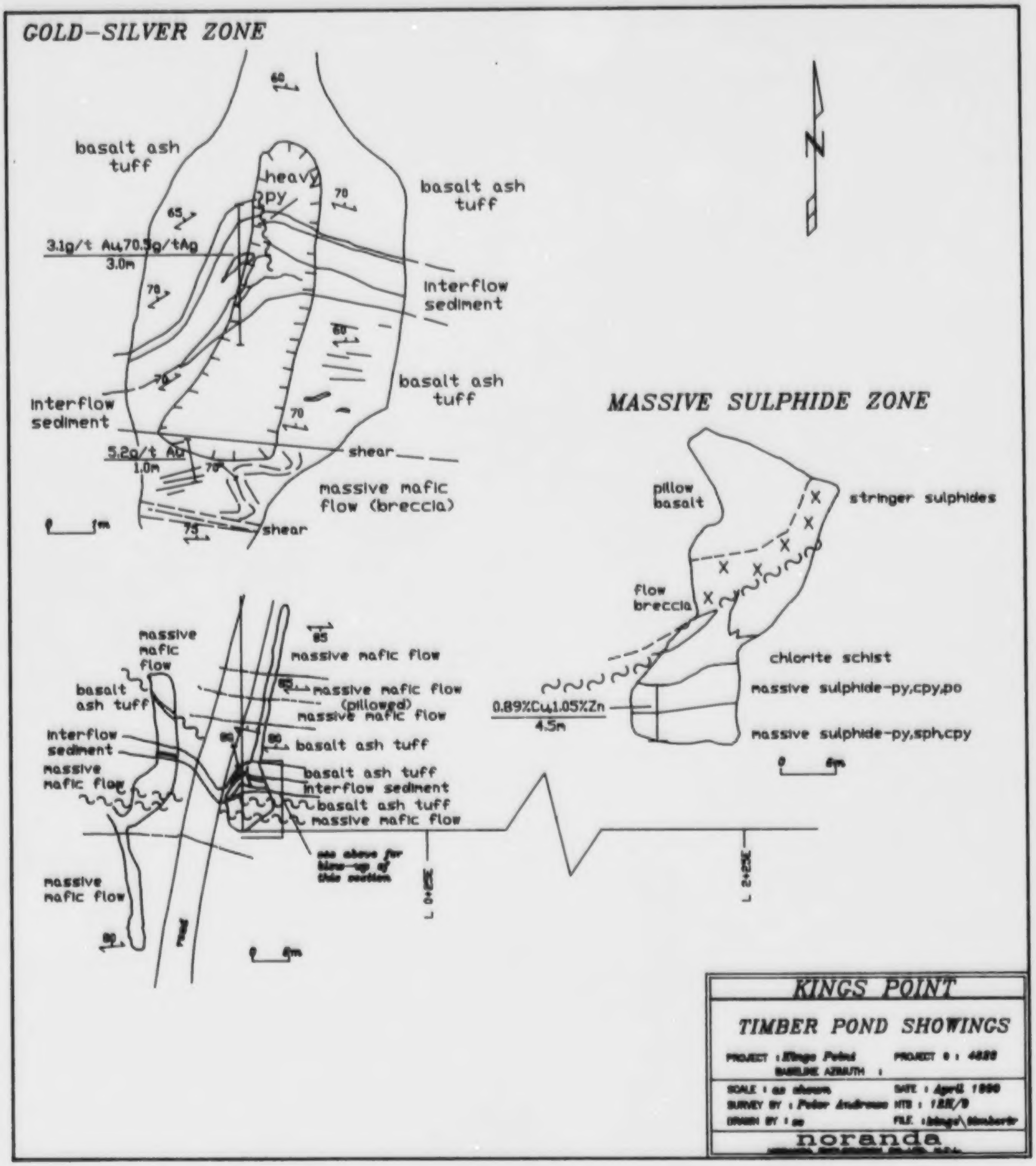

GOLD–SILVER ZONE
basalt ash tuff
heavy py
basalt ash tuff
3.1g/t Au,70.5g/tAg
3.0m
interflow sediment
basalt ash tuff
interflow sediment
5.2g/t Au
1.0m
shear
massive mafic flow (breccia)
shear
0 1m
N
MASSIVE SULPHIDE ZONE
pillow basalt
stringer sulphides
flow breccia
chlorite schist
massive sulphide-py,cpy,po
0.89%Cu,1.05%Zn
4.5m
massive sulphide-py,sph,cpy
0 6m
massive mafic flow
basalt ash tuff
interflow sediment
massive mafic flow
massive mafic flow
massive mafic flow (pillowed)
massive mafic flow
basalt ash tuff
basalt ash tuff
interflow sediment
basalt ash tuff
massive mafic flow
massive mafic flow
see above for blow-up of this section
L 0+25E
L 2+25E
0 6m
KINGS POINT
TIMBER POND SHOWINGS
PROJECT : Kings Point
BASELINE AZIMUTH :
SCALE : as shown
DATE : April 1990
SURVEY BY : Peter Andrews
NTS : 12H/9
noranda

Figure 70. *Sketch maps of trenches on the Timber Pond prospects. The gold—silver zone is on the left and the massive sulphide showing is on the right (see Andrews and Walker, 1990).*

representing an auriferous chemical and clastic sediment that was distal to the massive sulphide accumulation.

Mineralization in Sediments Overlying the Lushs Bight Group

Interflow and interpillow red chert and lenses of red chert and jasper characterize the top part of the Lushs Bight Group. The chert contains magnetite as disseminations and discrete bands. In places, the magnetite forms lenses up to 0.5 m thick.

The chert-bearing mafic volcanic rocks are overlain by 50 to 100 m of siliceous, chocolate brown argillite and interbedded ferruginous chert, grey-black argillite and green sandstone. The sediments, in particular the argillite, locally host stratiform bands and lenses of pyrite, pyrrhotite, magnetite and rare chalcopyrite. The sedimentary stratigraphic section is best preserved at Fox Neck and the mineralization is herein termed the Fox Neck type.

Fox Neck type deposits are best exemplified by the Nickey's Nose, Rushy Pond (Wheeler's Shaft), Rushy Pond Head and Fox Neck showings. They consist of both discrete massive pyrite bands and minor to extensive disseminated pyrite in an essentially argillaceous matrix. Massive magnetite beds up to 30 cm thick are present locally. The mineralized zones or bands are up to 10 m thick, and are locally traceable for up to 100 m (e.g., Nickey's Nose). Discontinuous outcrops of the mineralization persist for approximately 2 km along strike between the Nickey's Nose and Rushy Pond Head showings. The mineralization at Fox Neck consists of a 30-cm-thick bed of pyrite and pyrrhotite and a band of magnetite a few centimetres thick having a combined strike length of about 10 m. None of the mineralizations contains significant base- or precious-metal values (Table 8).

Nickey's Nose (North and South)—Rushy Pond—Rushy Pond Head Prospects (NTS 2E/12 Pyr013 and 014, Cu036, Pyr015)

Location

The four prospects all occur on the Harry's Harbour peninsula. The Nickey's Nose prospects can be reached via the Green Bay shoreline from Nickey's Nose Cove. The mineralized section should be visited at low tide for best viewing of the banded sulphides. The Rushy Pond (Wheeler's Shaft) prospect occurs at the northeast end of Rushy Pond and on the north side of the highway approximately 2.5 km south west of Harry's Harbour. The shaft is immediately to the north of the highway on the side of a steep hill. The Rushy Pond Head prospect is located on the north side of Western Arm approximately 1 km south of Highway 391 and 2.5 km southwest of the community of Harry's Harbour. The prospect can be best reached by boat, but is also accessible by foot from the road.

History of Development and Production

The Nickey's Nose, Rushy Pond and Rushy Pond Head prospects are all located in the Tasker and James Cook Fee Simple Grant, which was granted on December 14, 1917. A geological and geophysical survey of the Fee Simple Grant was conducted by Lundberg (1937). However, work on the mineralized sections was largely restricted to the Rushy Pond (Wheeler's Shaft) prospect. Lundberg (1937) described the Wheeler's Shaft as a mineralized zone prospected by a shallow shaft from which 25 tonnes of massive sulphide ore had been extracted. Old trenches were dug and shallow shafts were sunk on the other prospects but there is no record of development or production.

Peters (1970) noted the occurrence of sulphide mineralization within shear zones developed in argillites at the base of the Western Arm Group. Since then, the prospects have been the subject of several geological, geochemical and geophysical surveys without encouraging results.

Local Geology and Mineralization

The prospects are all associated with a red chert (jasper)—brown argillite sequence overlying mafic volcanic rocks of the Lushs Bight Group. This sedimentary sequence is overlain by pyroxene-crystal tuffs of the Western Arm Group.

The Lushs Bight Group in these areas consists of a fault-disrupted sequence of blackish-green agglomerate, pillow breccia, pillow lava and tuff. Epidote is extensive in fractures, vug and veins, and replaces the interclast matrix to the agglomerates. Gabbro, diabase and minor felsic dykes in the sequence are probably related to the overlying Western Arm Group. Interpillow jasper and jasper lenses become more common in the top of the volcanic sequence. The overlying sedimentary sequence is marked by jasper lenses and a sequence of interbedded, red-brown argillite, jasper, black and green argillite and sandstone. A thin unit of basaltic agglomerate or pillow breccia and interstitial jasper is present within the sedimentary rocks in some of the areas.

Stratabound, banded, massive to highly disseminated pyrite, minor pyrrhotite and rare chalcopyrite occur in the sedimentary rocks (Plate 36). Magnetite is usually found in the jasper and black sediments. The mineralized zone is approximately 10 m thick and is exposed for about 100 m; however, the same mineralized horizon has a strike length of over 2 km between Nickey's Nose and Rushy Pond Head. The mineralization in the Nickey's Nose area occurs at two localities (Nickey's Nose North and South) that are interpreted to be structural repetitions. Douglas *et al.* (1940) reported 0.02 oz/ton (0.7g/t) Au in a grab sample from Nickey's Nose North. Mineralization at Rushy Pond (Wheeler's Shaft) and Rushy Pond Head occurs at the same stratigraphic level and is of the same type. The Rushy Pond Head showing is traceable almost to Rushy Pond, a strike length of about 0.5 km. The sulphide bands locally show tight isoclinal folds that are also reflected in the facing directions in the sedimentary rocks.

Yogi Pond (NTS 12H/9 Pyr001)

Location

The showing is located approximately 1.5 km east of the King's Point highway in the bed of a brook about 300 m south of Yogi Pond. A forest access road parallels the north bank of the brook and a short walk across old cutover leads to the brook.

History of Development

The showing and surrounding area was explored in detail by BRINEX in 1962 (Roderick, 1962). At that time, geological, geochemical and geophysical surveys were carried out in the vicinity of the showing. A nickel anomaly was traced along strike for 140 m in either direction, however, no anomalous copper values were reported. The area was included in an M.Sc. thesis (DeGrace, 1971) that examined the structural and stratigraphic setting of the sulphide deposits in the area.

Local Geology and Mineralization

The showing occurs in bedded green tuffaceous rocks near the top of, or overlying, the Lushs Bight Group. The showing is in a setting similar to the Fox Neck type, although the host rocks are not identical. The showing consists of minor bands and disseminations of pyrite with rare chalcopyrite and magnetite in a fine-grained, green and black chlorite schist derived from tuffaceous rocks.

DeGrace (1971) described the showing as follows:

> "The schist zone is about 30 feet wide and strikes east-west, dipping steeply northward at its only exposure in the stream bed. Mineralization is almost entirely pyrite in disseminated bands reminiscent of depositional textures, and the walls of the schist zone are both of tuff. In thin-section the pyrite is poorly banded and follows poorly-defined fold patterns to which the strain-slip schistosity is axial planar.... F_3 folds with associated kink bands are present on a microscopic scale and do not appear to affect the distribution of sulphide mineralization."

The sulphide bands locally show tight isoclinial folds that may represent soft sediment deformation and/or dragfolding as suggested by MacLean (1947).

Vein-Hosted Mineralization

A number of significant vein-hosted showings and indications occur within the study area. These vein systems are typically developed within chlorite-schist zones and are not lithologically restricted. The veins appear to be largely structurally controlled and exhibit pinch and swell structures and *en echelon* arrays. Where this style of mineralization is developed in proximity to the chlorite-schist-hosted massive sulphides, the origin and relationship of the veins to the sulphides is obscure. Elsewhere, the veins are classified as structurally controlled mesothermal lode-gold vein systems related to regional metamorphic and deformational processes.

The veins are generally composed of a relatively simple mineralogy consisting of quartz—carbonate—pyrite and may carry significant gold, base metals and silver.

Hearn Gold Prospect (NTS 2E/12 Au001)

Location

The Hearn Gold prospect is located on the west side of Little Bay, just east of the highway to Beachside. Trenches and other workings are visible from the highway.

History of Development

The prospect, discovered in 1932 by a Little Bay prospector named Thomas Armstrong, is situated within the T. Hearn Fee Simple Grant (Volume 1, Folio 24) (Snelgrove, 1935). Armstrong found the prospect while following up a copper-carbonate float discovery by Thomas Hearn. Numerous shallow trenches and over a dozen test-pits were developed when Snelgrove (1935) investigated the property (Figure 71).

In 1939, the Geological Survey of Newfoundland commissioned Geophysical Exploration Limited to conduct a geophysical survey of the property (MacLean, 1947). Spontaneous polarization contours vaguely outlined the

Plate 36. *Banded pyrite, Nickey's Nose prospect.*

sulphide mineralization and one minor anomaly approximately coincided with Pit No. 5. The Geological Survey of Newfoundland drilled three diamond-drill holes on the property in 1941; however, these failed to extend the mineralization beyond what was observed on surface (MacLean, 1947).

Northern Canada Mines Limited optioned the property and carried out extensive geological, geophysical and follow-up diamond drilling (Brown, 1963). They examined the potential for base metals within the shear zone because of the similarity to the shear zone hosting the Little Bay Mine. The option was dropped after discouraging results.

Local Geology and Mineralization

The prospect is hosted by chlorite schist developed within the sheeted dyke-pillow lava transition zone of the Lushs Bight Group. The contact with pillow lava is only a few tens of metres away and numerous pillow lava screens are present. Shearing and chlorite schist are inhomogeneously developed and the pillow screens generally take up most of the deformation. The chlorite-schist zone parallels the contact.

The chlorite-schist zones are up to 2 m wide and are intermittently developed over a distance of 1 km or more. The mineralization is intermittentlydeveloped in the chlorite schist and occurs as disseminations and veins up to 4 cm thick. It also occurs as quartz—carbonate veins and veinlets (Plate 37). Pyrite, chalcopyrite, sphalerite, arsenopyrite, galena and gold are present in that order of abundance. There is no visible gold, but it occurs associated with arsenopyrite, sphalerite and minor galena (Snelgrove, 1935) (Table 17).

Snelgrove (1935) described the mineralized zone as consisting of andesite-hosted chlorite schist containing abundant sulphides and "numerous, small parallel veins and lenses of sulphide bearing quartz." He noted that the alteration is typically chloritic; however, hydrothermally produced silica and carbonate are also present. Snelgrove (1935) described the mineralization and mineralogy as follows:

> "The best mineralization exposed at the time of examination occurs in pits 2, 4, and 5, ... representing a distance of 250 feet along the strike.
>
> In pit 2 gossan extends to three feet below the surface; below this chloritic and partly carbonatized and silicified schist over a thickness of four and a half feet is impregnated with pyrite and contains several massive pyrite veins up to four and a half inches wide. This schist also contains quartz veinlets banded with pyrite, sphalerite, galena, and chalcopyrite. The schistosity forms two conjugate systems, the general dip of which is northward at high angles.
>
> Pit 4 contains similar schist with parallel quartz veins up to 6 inches in width. The quartz is mineralized with pyrite, sphalerite, a little chalcopyrite and some marcasite.

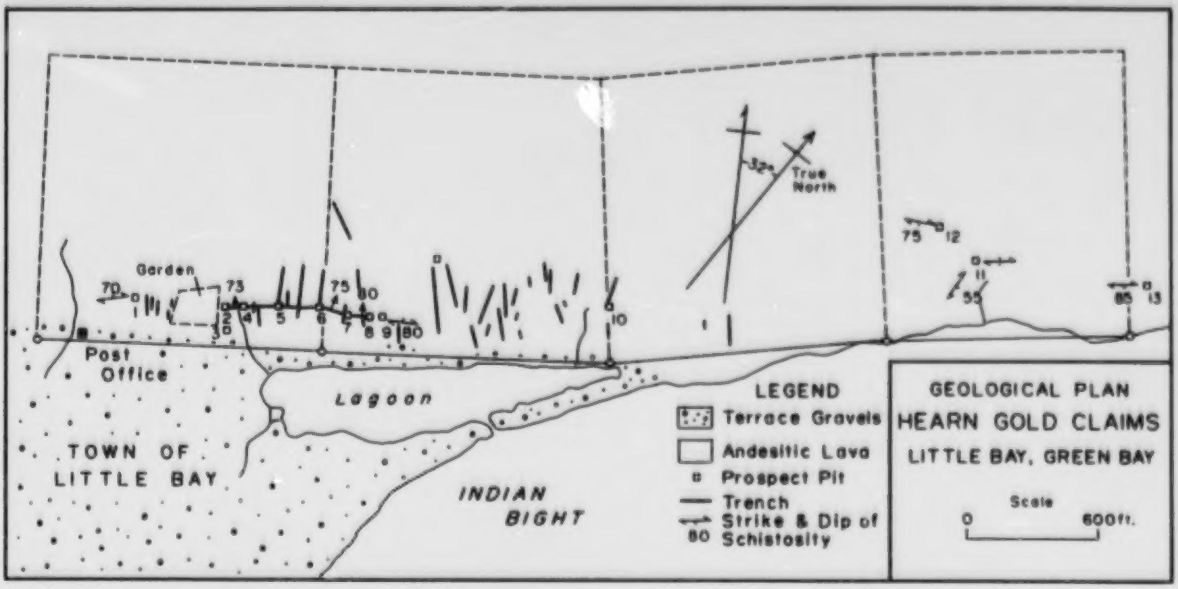

True North
32°
Garden
70
73
75
80
1
2
3
4
5
6
7
8
9
10
11
12
13
55
75
85
80
Post Office
Lagoon
TOWN OF LITTLE BAY
INDIAN BIGHT
LEGEND
Terrace Gravels
Andesitic Lava
Prospect Pit
Trench
Strike & Dip of Schistosity
80
GEOLOGICAL PLAN
HEARN GOLD CLAIMS
LITTLE BAY, GREEN BAY
Scale
0
600ft.

Figure 71. *Sketch plan of the Hearn gold prospect, Little Bay (see Snelgrove, 1935).*

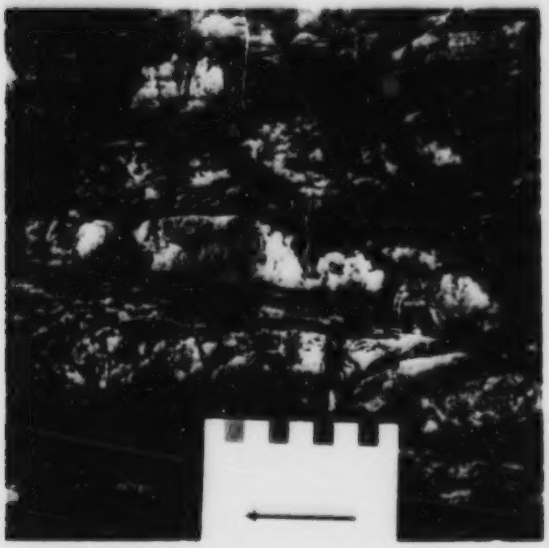


Plate 37. *Gold-bearing quartz-carbonate veins in chlorite schist, Hearn Prospect (ca. 1983).*

> Pit 5 reveals over 6 feet of pyritic chlorite schist, somewhat carbonatized, and several veinlets of quartz containing pyrite, galena, and minor amounts of sphalerite with ex-solution chalcopyrite.
>
> East and west of the above-described pits, the lava as exposed in the other pits and trenches along this zone is less sheared and less mineralized. The sulphides consist chiefly of pyrite and chalcopyrite. Pit 12 appears to be on an independent shear zone, one and a half feet in width, mineralized with pyrite, and a little chalcopyrite, with very little quartz. Pit 13 reveals a shear zone 1 foot wide containing quartz, calcite, pyrite, chalcopyrite, sphalerite, coveliite, and earthy hematite. Pit 3 is sunk on an independent shear zone paralleling the main zone, and contains a quartz vein several inches in width, mineralized with pyrite and chalcopyrite."

MacLean (1947) described the prospect as consisting of quartz-pyrite veins and veinlets introduced into sheared, chloritic and brecciated metabasaltic pillow lava and dolerite dykes.

The following excerpt from MacLean (1947) describes the mineralogy of the prospect.

> "The veins contain quartz and carbonate (mostly calcite), with associated sulphides. The metallic minerals, in order of abundance, are pyrite, sphalerite, chalcopyrite, arsenopyrite, galena, and gold. Supergene minerals are represented by rare limonite, malachite, and covellite. The veins always contain shreds of unreplaced chlorite with the quartz and sulphides. Some of the veins show banded sulphides; one shows several one-inch bands of coarse pyrite, with interstitial quartz, alternating with quartz-rich one-inch bands containing disseminated arsenopyrite.

Table 17. Assays of samples from the Hearn Prospect (modified after Snelgrove and Howse, 1934)

Pit No.*	Kind of Sample	Width ft.	 in.	Gold per ton dwt.	 gr.	Silver per ton dwt.	 gr.
1	Grab	0	1	nil		-	
2	Channel	4	6	nil		nil	
4	Channel	2	3	trace			
4	Selected	n.a.		5	5.44	7	11.84
5	Channel	6	6	1	7.36	11	18.24
5	Selected	n.a.		10	10.88	15	16.32
5	Channel**	4	2	1	7.36	9	7.52
5	Channel	4	6	9	7.52		
6	Channel	6	6	nil		-	
7 Dump	Grab	n.a.		nil		-	
8 Dump	Selected	n.a.		nil		-	
13 Dump	Selected	n.a.		trace		-	

* Pits are numbers consecutivley from west to east. ** Assays for arsenic and lead are nil. n.a.-not available.

.....samples that show gold and silver assay values come from two adjoining pits, Nos. 4 and 5, which are 150 feet apart and on the main mineralized shear zone. Arsenopyrite and gold seem to be the only localized minerals. Microscopic grains of arsenopyrite were observed in all specimens from the pits mineralized with gold and silver, but this mineral was not seen in ore from the 11 other pits. Gold was seen in microscopic grains in only one sample, from Pit No. 4.

Gold is found only in the ores carrying arsenopyrite. The gold is associated with sphalerite and a little galena. The arsenopyrite appears to have been one of the first minerals to have formed; the gold is apparently the last. The presence of the much earlier arsenopyrite possibly had some effect on the late mineralizing solutions, causing precipitation of gold.

The pyrite, arsenopyrite, and quartz are strongly fractured in some parts of the shear zone; these fractures are cemented by quartz, chalcopyrite, sphalerite, and galena. This suggests some movement along the fault zone after the deposition of the bulk of the pyrite and quartz."

Mine Brook (NTS 12H/9 Au001)

Location

The showing is located approximately 1 km south-southwest of the southern end of Big Deer Pond on the north bank of Mine Brook. It can be reached by an old woods road from the Little Bay highway at the north end of Davis Pond. The road comes within about 1 km of the showing.

History of Development and Production

The date of its discovery is unknown. However, when rediscovered by BRINEX in 1962, previous trenching and stripping was evident. Further trenching and a program of geological mapping, geochemical soil sampling and geophysical surveying (magnetic, EM, SP) was carried out (MODS 12H/9, Au001). In 1969, two Winkie drillholes gave assays of <1.4 g/t Au (Roderick, 1962). In 1980, further geochemical and geophysical surveys were conducted. Three holes were drilled, one with an intersection of 8.2 g/t Au over 1.52 m (Lohman *et al.*, 1985). In 1984, trench sampling gave assay values of up to 62 g/t Au (Tuach, 1987).

Local Geology and Mineralization

The showing is hosted by sheared and altered massive to pillow basalt and possibly minor intercalated tuff of the Lushs Bight Group. Minor felsite dykes are also present. The mineralization occurs within a northeast-trending, steeply north-dipping, shear zone defined by chlorite and quartz—carbonate—sericite schist along Mine Brook. If has a strike length of at least 450 m and width of 1 to 60 m.

BRINEX geologists described the showing as consisting of finely disseminated pyrite and arsenopyrite with gold and silver values, hosted by grey quartz veins and lenses within a zone of quartz—carbonate—sericite schist. A gossan zone, immediately to the east, contains pyrite and chalcopyrite in pillow basalts.

Gold mineralization is associated with pyritized siliceous zones within both the chlorite schist and quartz—carbonate—sericite schist. The siliceous host contains carbonate and 2 to 8 percent sulphides. It varies in width from 10 to 60 cm with well-developed pinch-and-swell structures (Lohman *et al.*, 1985). The mineralized siliceous zone is interpreted to be a silicified and hydrothermally altered mafic volcanic rock.

The Hammer Down Deposit (NTS 12H/9 Au009)

Location

The Rendell-Jackman Hammer Down gold deposit is located approximately 12 km northwest of the town of Springdale. The prospect can be reached by a forest access road, which leads southwestward from the King's Point highway, and by a short walk along a muskeg trail.

History of Development

The Hammer Down deposit was discovered by Noranda in 1987 after successfully following up a number of anomalous geochemical and geophysical trends. Exploration to date involving trenching and diamond drilling has led to the discovery of a series of auriferous quartz veins, in four main zones now known as the Hammer Down, Rumbullion, Muddy Shag and Wistaria zones (Figure 72). The most significant concentration of these veins occurs within the main Hammer Down deposit.

Local Geology and Mineralization

The gold mineralization is hosted within a series of vertical, moderately plunging, sulphide-bearing quartz veins hosted within sheared mafic volcanic and sedimentary rocks (Figure 73) and intercalated microgabbros of the Catchers Pond Group. Fine- to medium-grained felsic porphyry dykes are common.

The following description of the structure and mineralization is taken from Andrews (1990).

> "All rock types in the deposit area have been affected by varying degrees of deformation and range from being weakly sheared and foliated to strongly mylonitic. There is a general NE-trending, vertical to subvertically dipping cleavage developed in the majority of rocks on the property. However, this is subject to local fluctuations due to both large and small scale folding and faulting. A system of broad assymetrical folds is evident from geophysical trends which correlate well with smaller outcrop scale parasitic folds. In general these folds plunge moderately to the SW. Locally, F_2 is developed which plunges more shallowly to the NW.
>
> At the Hammer Down Deposit the mineralized quartz veins are steeply-dipping and appear to be folded in an east-verging pattern indicating a major fold closure further to the east. These folds generally plunge moderately to the SW at −60°. Lineations on the walls of the quartz veins indicate a vertical component of movement possibly associated with later faulting. At depth, the veins anastomose as well as pinch and swell, similar to patterns noted on surface outcrop. Whereas the veins on the Hammer Down Deposit appear folded, elsewhere (e.g., at the Rumbullion Zone), the veins do not appear to be folded but are in fact axial planar to folds in the mafic host rocks. Narrow mineralized veins at the Wistaria Zone, south of the Hammer Down Deposit, are strongly folded and occur in the hinge of a large, shallowly plunging fold. These and other structural inconsistencies require much further detailed analysis in order to develop a cohesive model for the structural history of the area.
>
> A number of faults disrupt the deposit area. These are expressed as airphoto lineaments, "breaks" in geophysical trends and in outcrop and drill core as fault gouge, slicken-sides and offsets. In general, these faults appear to be steeply-dipping and trend to the NE; however, crosscutting faults are noted.
>
> To the north of the property, the Green Bay Fault, a major NE-trending feature, defines the western limit of the Springdale Peninsula. A large

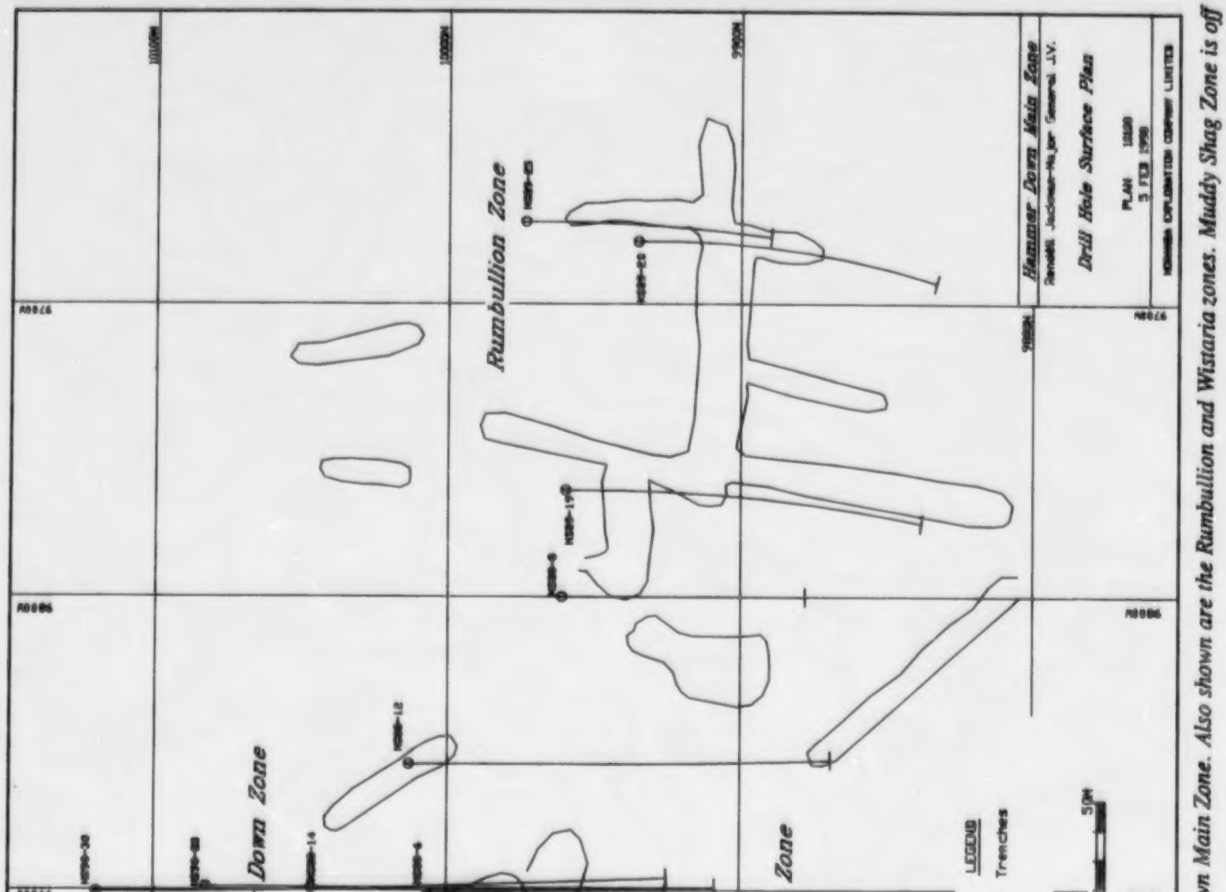

Hammer Down Main Zone
Randall Jackson-Major General J.V.
Drill Hole Surface Plan
PLAN
Rumbullion Zone
Hammer Down Zone
Wistaria Zone
LEGEND
Trenches
0
50M
10100N
10000N
9900N
9800N

Figure 72. *Sketch map of trenches in the area of the Hammer Down Main Zone. Also shown are the Rumbullion and Wistaria zones. Muddy Shag Zone is off the figure to the southwest (left) (see Andrews, 1990).*

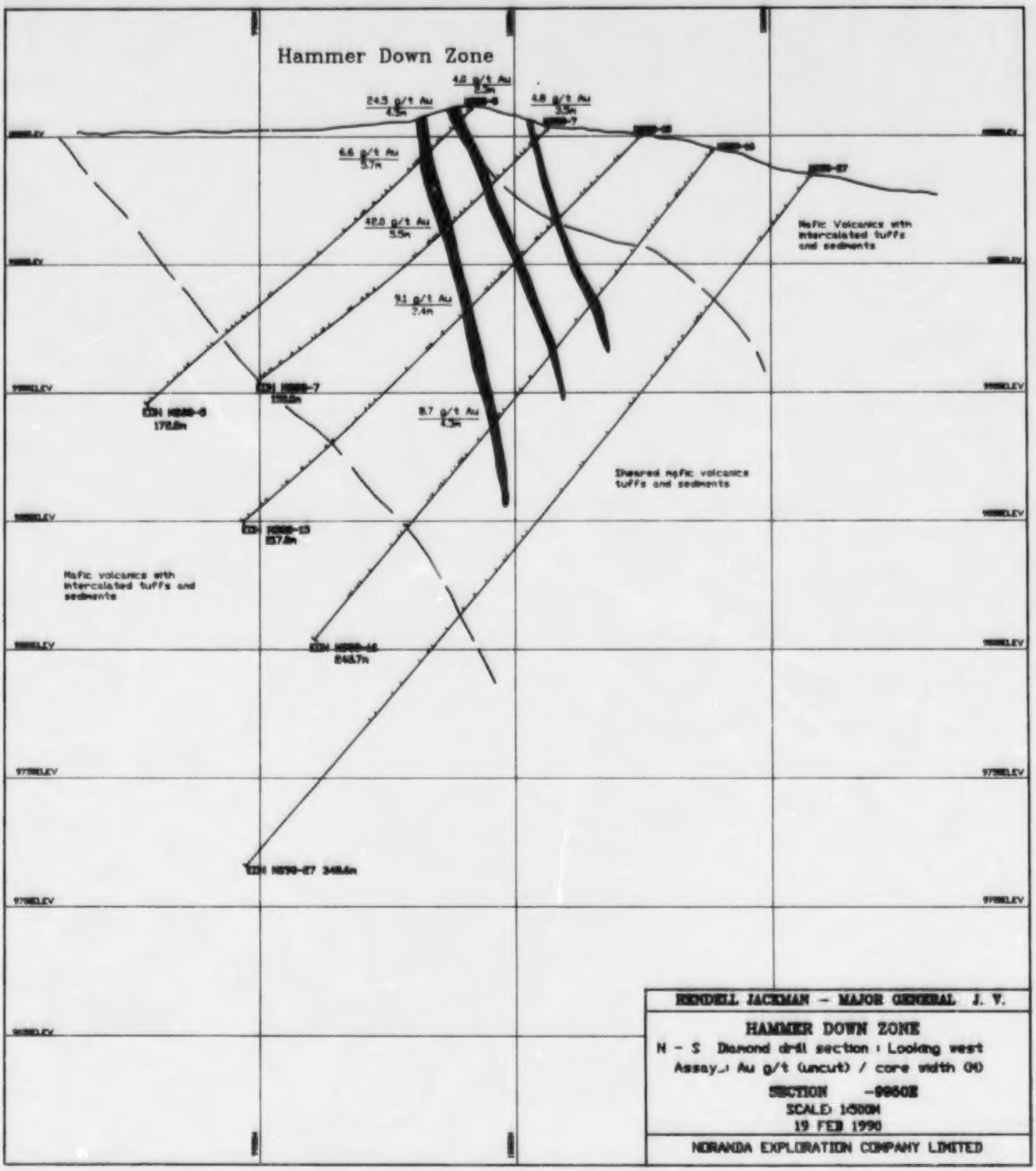

Hammer Down Zone
24.5 g/t Au 4.5m
4.0 g/t Au 2.5m
4.8 g/t Au 3.5m
4.6 g/t Au 3.7m
42.0 g/t Au 5.5m
9.1 g/t Au 7.4m
8.7 g/t Au 4.3m
Mafic Volcanics with intercalated tuffs and sediments
Sheared mafic volcanics tuffs and sediments
Mafic volcanics with intercalated tuffs and sediments
RENDELL JACKMAN – MAJOR GENERAL J. V.
HAMMER DOWN ZONE
N – S Diamond drill section : Looking west
Assay : Au g/t (uncut) / core width (M)
SECTION -9950E
SCALE: 1:500M
19 FEB 1990
NORANDA EXPLORATION COMPANY LIMITED

Figure 73. *North—south cross-section through the Hammer Down Main Zone, looking west. Mineralized zones are solid black (see Andrews, 1990).*

sub-parallel splay off this fault projects along the northern limit of the Rendell-Jackman property and may be responsible for many of the structural features developed within the Hammer Down Deposit.

The Hammer Down Deposit occurs within sulphide-bearing quartz veins. These veins are found within all rock types present in the deposit area, including mafic flows, tuffs, microgabbros and felsic porphyry dykes. The quartz veins tend to be closely associated with contact zones, faults and shear zones within these units.

Mineralization is hosted by moderately to intensely sheared quartz veins which often exhibit several different stages of crystallization. There is local evidence for multiple veining events; however, recrystallization has obliterated most vein textures.

Patches of fine grained sericite are variably distributed throughout the veins and minor chlorite is associated with pyrite and sericite. Carbonate occurs in varying proportions and is associated commonly with the sulphides.

Pyrite is the dominant sulphide mineral present and occurs as fine to coarse grained, disseminated clusters and aggregates of subhedral to euhedral crystals throughout the quartz veins. In many instances, pyrite grains occur in veinlike distribution is an anastomising fasion. Minor amounts of chalcopyrite, sphalerite and galena have been observed in the quartz veins. Rutile occurs as fine grained disseminated anhedral clusters within sericitic patches.

Sulphide percentages in the quartz veins vary from <5% to near massive proportions of up to 75% sulphides. In general, the higher the proportion of sulphides, the higher the grade of gold in the quartz veins. The majority of gold occurs enclosed within pyrite grains. Lesser amounts occur at pyrite-pyrite grains boundaries, pyrite-gangue grain boundaries and gangue-gangue contacts. Coarse gold represents a small percentage of total gold, and visible gold is rare, generally restricted to parts of the veins where the majority of sulphide minerals has been oxidized.

To date, the gold-bearing structure has been traced by trenching and diamond drilling, for 1,100 m along strike and to a vertical depth of 225 m, and is open to the east and at depth. Recent calculations (April, 1990) estimate geological reserves (undiluted) in the Hammer Down Deposit to stand at 429 593 tonnes grading 11.6 g/t Au (cut to 34.3 g/t) or 19.5 g/t Au (uncut).

The rocks hosting the Hammer Down quartz veins do not generally exhibit strong alteration patterns. The mafic rocks are weakly to moderately chloritic, and commonly contain minor carbonate and epidote. Strongly deformed zones are characterized by chlorite schists in which elevated proportions of chlorite, carbonate, epidote and minor talc alteration occur, especially in association with quartz-carbonate brecciation. Leucoxene is a common alteration product in the microgabbros, occurring as small lathe-like crystals which are commonly preferentially aligned to define a distinct foliation.

Felsic porphyritic rocks are generally very siliceous with minor sericite and chlorite alteration of phenocrysts and along fracture planes. Again, in strongly deformed areas, fold and faults, the degree of alteration increases substantially."

Recent calculations (March, 1995) estimate geological reserves in the Hammer Down deposit to stand at 440 000 tonnes grading 16.91 g/t and in the Rumbullion deposit to stand at 122 440 tonnes grading 24.62 g/t Au (Major General Resources Limited, Press Release March, 1995).

Silverdale (Bear Cove) (NTS 2E/12 Pb001)

Location

The prospect is located on the north side of Western Arm, within the community of Silverdale.

History of Development

The Bear Cove lead mine (now known as Silverdale) in Green Bay was owned by William Cook and three other men, including John R. Stewart. Apart from a few sporadic attempts, however, the Bear Cove property lay essentially unexplored until Stewart optioned it in 1907 to a novice engineer, James Campbell (Martin, 1983). Campell formed the Bear Cove Mines Company Limited in 1907 and in 1908 dewatered an old shaft sunk by the Newfoundland Exploration Syndicate in 1905. The operation again closed in the fall of 1908. MacLean (1947) described the development as consisting of an 18 m shaft, with a 9 m drift at the 9 m level, sunk within sheared pillow lavas. Lundberg (1937) completed a geological and geophysical survey in the area in 1936.

The property was examined by Minorex Limited in 1980 and 1981. They conducted detailed geological mapping, geophysical and geochemical surveys and drilled 7 holes totalling 202 m. Diamond drilling in both directions along strike failed to intersect any lateral or vertical extension of the mineralization; however, the host breccia zone was intersected. Minorex (1981) suggested that the mineralization may plunge along the strike of the brecciated zone.

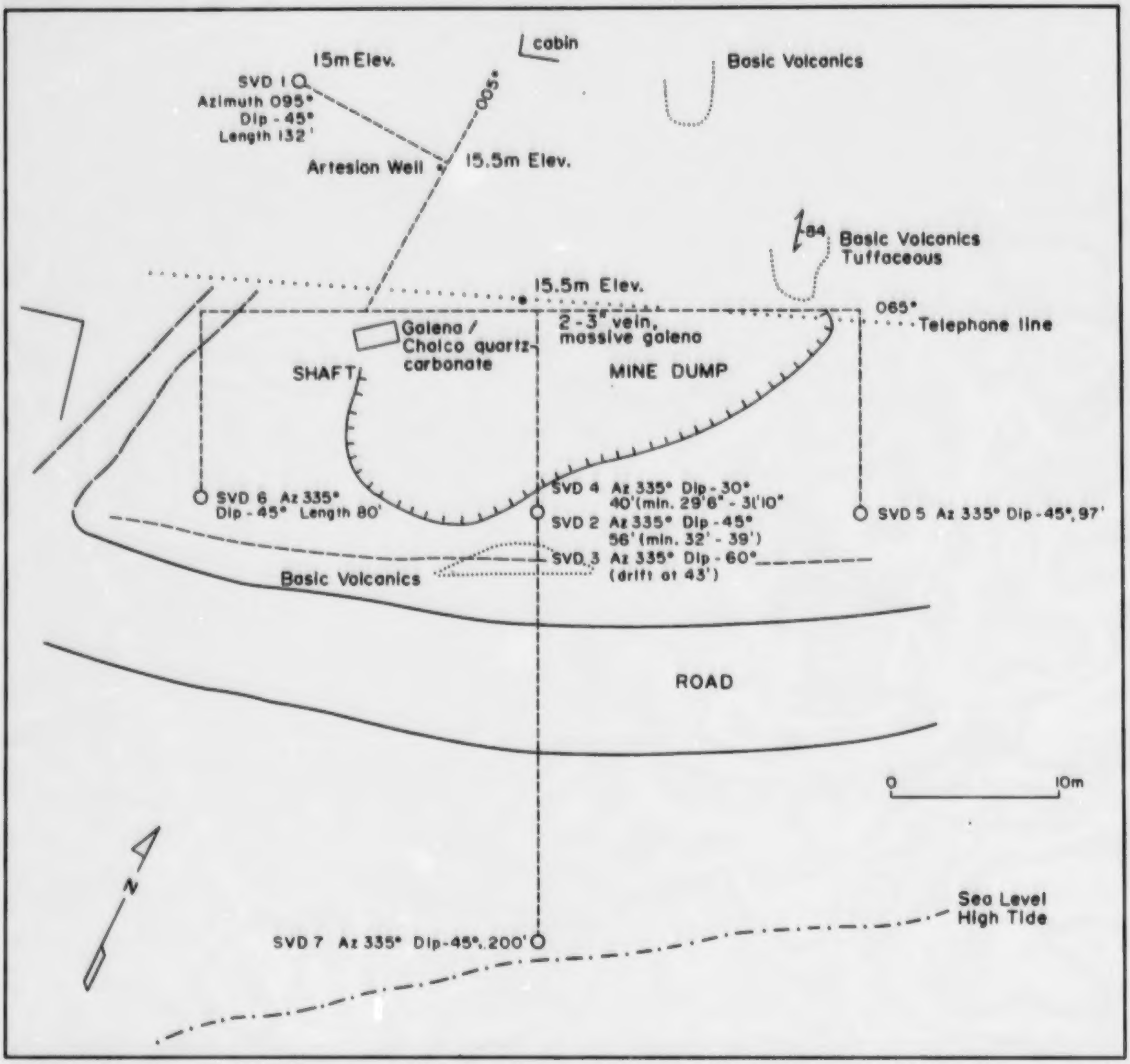

cabin
15m Elev.
SVD 1
Azimuth 095°
Dip - 45°
Length 132'
005°
Basic Volcanics
Artesian Well
15.5m Elev.
84
Basic Volcanics
Tuffaceous
15.5m Elev.
065°
Telephone line
Galena /
Chalco quartz-
carbonate
2 - 3" vein,
massive galena
SHAFT
MINE DUMP
SVD 6 Az 335°
Dip - 45° Length 80'
SVD 4 Az 335° Dip - 30°
40'(min. 29'6" - 31'10"
SVD 2 Az 335° Dip - 45°
56' (min. 32' - 39')
SVD 3 Az 335° Dip - 60°
(drift at 43')
SVD 5 Az 335° Dip - 45°, 97'
Basic Volcanics
ROAD
0
10m
N
Sea Level
High Tide
SVD 7 Az 335° Dip-45°, 200'

Figure 74. *Geological sketch plan and diamond-drill hole location plan for the Silverdale area (see Minorex, 1981).*

Local Geology and Mineralization

The prospect is hosted by sheared and chloritized pillow basalts of the Lushs Bight Group. MacLean (1947) described the mineralization as consisting of quartz— carbonate veins carrying disseminated pyrite, chalcopyrite, galena and tetrahedrite hosted by a subsidiary shear of the Southwest Brook-Nickey's Nose fault.

Minorex (1981) described the mineralization as being associated with a quartz-carbonate veined, breccia zone developed within sheared pillow lava (Figures 74 and 75). The shear zone subparallels a fault extending from Bear Cove to Nickey's Nose Point. The mineralization is probably not of volcanogenic origin and may be epigenetic. Massive patches of galena and chalcopyrite with silver and traces of gold (Table 18) are hosted by quartz—carbonate veins or stockwork. Quartz—carbonate also forms the matrix to the breccia. Sulphide veinlets ranging from 5 to 7.5 cm are developed locally. Minorex (1981) reported the mineralization to be quite variable with grab samples from the old dump assaying between 25.98 and 134 oz/ton silver.

Two new lead occurrences, reported by Minorex (1981), are located 100 and 150 m on a bearing of 010° from the old shaft. These along with a third occurrence consisting of minor galena, occur in a zone defined by a lead soil anomaly (Minorex, 1981). The anomaly subparallels the fault zone.

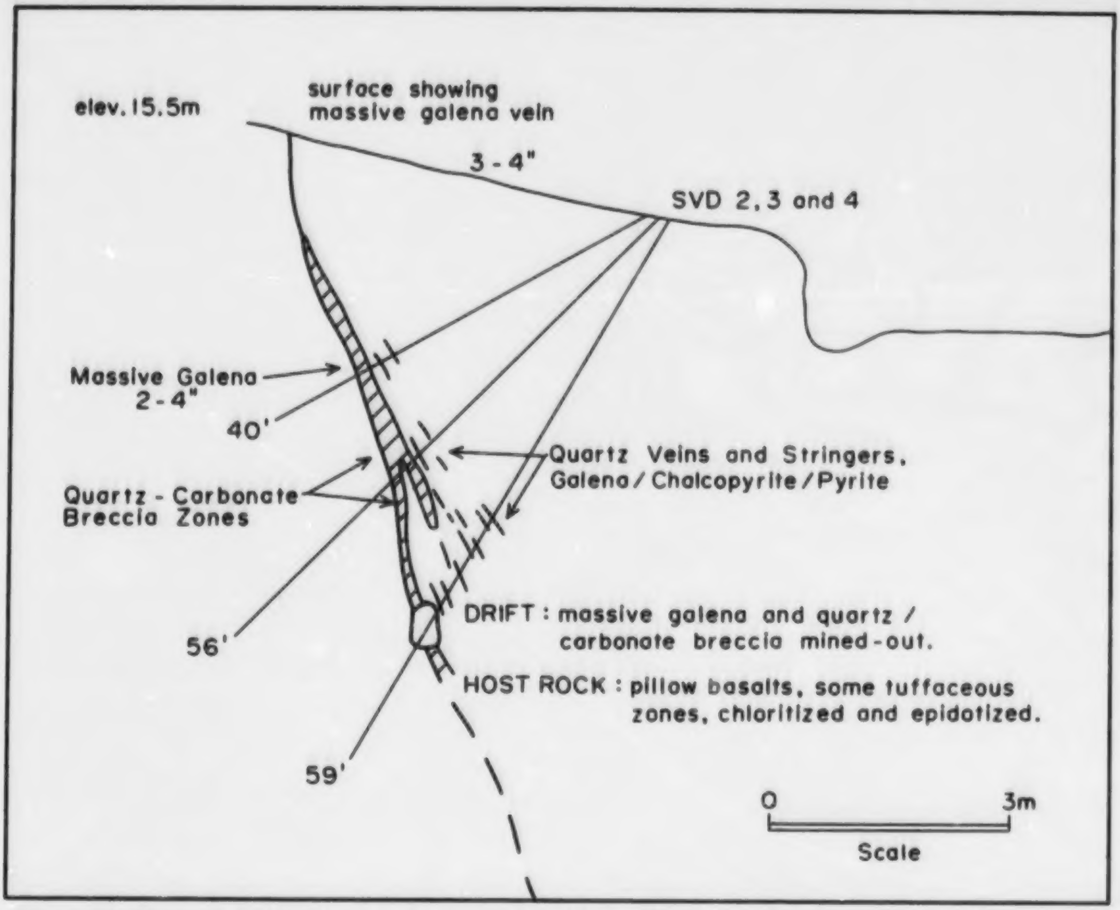

elev. 15.5m
surface showing
massive galena vein
3 - 4"
SVD 2, 3 and 4
Massive Galena
2 - 4"
40'
Quartz Veins and Stringers,
Galena / Chalcopyrite / Pyrite
Quartz - Carbonate
Breccia Zones
DRIFT : massive galena and quartz / carbonate breccia mined-out.
56'
HOST ROCK : pillow basalts, some tuffaceous zones, chloritized and epidotized.
59'
0
3m
Scale

Figure 75. *Diamond-drill hole section for diamond-drill holes SVD-2, 3, and 4, Silverdale (see Minorex, 1981).*

Table 18. Assay results from grab samples and diamond drilling on the Silverdale property (adapted from Minorex, 1981)

Sample Number	Footage	Cu%	Pb%	Zn%	Ag oz/ton	Au oz/ton
ST-1-AA	grab	2.63	26.5	0.42	134.00	0.038
ST-1-BC	grab	2.44	14.3	0.35	111.28	0.028
ST-2-BC	grab	1.98	27.5	0.37	112.96	0.030
SVD#4-81	30.0-31.0	0.11	1.82	0	2.89	-
	31.0-32.0	0.47	9.9	0	5.7	-
SVD#3-81	35.0-36.0	0.20	0.11	0	0.08	-
	37.0-39.0	0.02	0.31	0	0.34	-
SVD#2-81	31.8-33.8	0.21	1.18	0	0.61	-
	34.2-36.4	0.77	7.90	0	15.5	-
	36.4-38.4	0.31	1.09	0	1.39	-
	38.4-40.0	0.11	0.03	0	0.10	-

SUMMARY AND CONCLUSIONS

The Lushs Bight Group is a mafic volcanic sequence consisting predominantly of pillow basalt (locally massive basalt) and sheeted diabase dykes. Excellent examples of sheeted diabase dykes are preserved in widely scattered geographic areas that are generally separated by faults. Gabbroic dykes, sills and stocks and rare ultramafic rocks are also present.

The presence of sheeted dykes within the Lushs Bight Group attests to its ophiolitic, or at least extensional environment, affinity. The formation of ophiolites in non-ridge tectonic environments is now well documented, including supra-subduction zone settings during the earliest stages of island-arc formation (Gass, 1989; Pearce *et al.*, 1984b).

This study has documented that the Lushs Bight Group consists primarily of rocks having a well-developed, island arc tholeiites geochemical signature; however, boninitic and low-Ti rocks are also present. Although the tectonic setting for the formation of boninitic rocks is not clearly understood or agreed upon, (cf. Crawford *et al.*, 1989; Tatsumi and Maruyama, 1989) the conditions generally accepted as necessary for boninite formation, such as refractory mantle (harzburgitic), abundant water, high temperatures (1200°C), and low pressures (depths of segregation less than 15kb), are all met in a supra-subduction zone environment. A supra-subduction zone environment or setting involves one or more of: i) subduction of a spreading centre (Crawford *et al.*, 1989) ii) back-arc basin opening (Crawford *et al.*, 1989), and iii) initiation of subduction (Cameron *et al.*, 1979; Bloomer and Hawkins, 1987). Thus, the association of island-arc tholeiites and boninities is good evidence for a supra-subduction zone setting for the Lushs Bight Group. The MORB or non-arc dykes, appear to intrude all the geochemical groups within the Lushs Bight Group and may represent back-arc basin formations during rifting of the Lushs Bight Group.

The regional geology and chemo-stratigraphy of western Notre Dame Bay thus supports the interpretation that the Lushs Bight Group formed above a subduction zone during the early stages of island-arc formation, i.e., subduction-initiation. It also suggests that the Lushs Bight Group, as the early arc, was preserved in a fore-arc setting. This may also offer an explanation for some of the structural complexity and intensity and alteration of deformation found in the Lushs Bight Group.

The many base-metal mineral deposits found in the Lushs Bight Group differ greatly in size but most have several features in common. All are roughly ellipsoidal with their long axes approximately coplanar with bedding. They occur almost exclusively in chlorite-schist zones developed within the pillow lavas and associated tuff. They consist mostly of pyrite and lesser amounts of chalcopyrite, pyrrhotite, sphalerite and gold and minor values of silver.

The grades of the deposits vary from <1 to >10 percent copper, with high grade zones up to 20 percent. Most of the deposits have significant gold values (Tables 7 and 8), a feature that distinguishes the ophiolitic volcanogenic sulphides from the non-ophiolitic ones. Silver is present in the order of <1ppm to 25 ppm and lead is present in trace amounts. Zinc was not recovered or reported from most of the deposits; however, zinc is significant in the Little Deer mine where there appears to be a metal zoning (West, 1972) and is present in other areas such as the Timber Pond prospect. Zinc is also a significant component of similar deposits in other sequences such as the Bett's Cove (Saunders, 1985) and York Harbour mines (Duke and Hutchinson, 1974).

Deformation has obliterated all primary structures in most prospects and the sulphides are remobilized and recrystallized. High-grade copper zones are commonly present in the noses of folds. A good tectonic banding is developed in many cases, e.g., samples from the dump at Little Deer. However, a well-developed, mineral banding at the Rendell-Jackman prospect is interpreted to be primary. Many of the preserved records and many of the outcrops, glory holes, dump samples and drill-core display only disseminated and stringer sulphides. In many cases, this probably represents the extent and the nature of the original mineralization, i.e., it appears to have been within basaltic hydrothermal systems that never breached the surface. Peters and Smitheringale (1974) reported colloform and relict colloform textures in some of the sulphides, e.g., Sterling and Lady Pond, suggesting an on-surface or near surface deposition site.

The mineralization occurs at a number of different stratigraphic positions within the basalt sequence. Note that the boninitic lava or area of boninitic rocks are generally highly mineralized and a high number of mineral prospects occur in these general areas. Areas of variolitic and quartz amygdaloidal pillow basalt also occur in the mineralized areas. In fact, the boninitic lavas are generally variolitic. Mineralization at the Betts Cove Mine occurs at the sheeted dyke—pillow lava contact (Upadhyay and Strong, 1973). Mineralization at the York Harbour deposits occurs at a stratigraphic level at or near the contact between two pillow lava sequences (Duke and Hutchinson, 1974).

Mineralization at the top of the ophiolite sequence is perhaps represented by the Tilt Cove deposit. Rona (1984) also indicated that the deposition of sulphide deposits occur at different stratigraphic levels within the basalt pile.

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Note: Geological Survey file numbers are given in square brackets.

APPENDIX 1

LIST OF REPORTS ON THE LUSHS BIGHT GROUP

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Note: Geological Survey file numbers are given in square brackets.

APPENDIX 2

COMPLETE GEOCHEMICAL DATASET FOR THE LUSHS BIGHT GROUP, OVERLYING SEQUENCES AND INTRUSIVE ROCKS

Table 2-1. LUSHS BIGHT GROUP LAVAS*

Sample Field No. Rock Type	1542001 BK-82-002A lava	1542004 BK-82-004 lava	1542006 BK-82-008A agglom	1542011 BK-82-015A lava	1542013 BK-82-017A lava	1542016 BK-82-019A lava	1542018 BK-82-020A lava
SiO_2	51.35	51.78	57.19	53.45	52.29	53.05	49.69
TiO_2	0.83	0.85	0.90	0.89	0.86	0.92	1.29
Al_2O_3	16.89	15.67	14.25	15.45	15.39	14.53	16.68
FeO*	9.20	10.35	9.64	10.43	9.51	9.87	13.40
MnO	0.14	0.18	0.17	0.20	0.20	0.21	0.25
MgO	5.92	7.01	4.99	8.19	6.66	7.38	7.48
CaO	11.88	10.28	6.67	5.99	11.89	9.35	7.23
Na_2O	3.60	3.75	5.77	5.08	3.02	4.49	3.82
K_2O	0.13	0.08	0.37	0.27	0.13	0.11	0.08
P_2O_5	0.05	0.05	0.06	0.06	0.07	0.07	0.08
LOI	2.16	2.58	1.59	2.75	3.23	1.64	3.33
Cr	146	67	43	44	65	51	36
Ni	38	30	23	32	33	28	30
V	262	314	341	312	322	304	422
Cu	118	72	67	71	67	71	71
Zn	71	87	73	89	80	91	133
Rb	1	1	2	5		1	
Ba	62	11	134	55	51	72	79
Sr	199	105	96	109	109	126	36
Ga	14	14	12	1	12	9	1
Nb	1.0	0.8	2.0	1.0	1.8	0.5	0.9
Zr	36	37	39	40	35	38	53
Y	31	21	26	25	21	21	30
Th		0.22			0.15	0.18	0.21
La		1.38			1.77	2.06	
Ce		4.48			4.80	5.68	
Pr		0.74					
Nd		4.29			4.91	5.99	
Sm		1.72			1.98	2.16	
Eu		0.73			0.52	1.44	
Gd		2.51			2.61	4.34	
Tb		0.49					
Dy		3.52			3.86	4.34	
Ho		0.83					
Er		2.30			2.40		
Tm		0.33					
Yb		2.25			1.88		
Lu		0.33					

* Major elements in wt %; trace elements in ppm. Recalculated volatile-free to 100%.

Table 2-1. Continued

Sample Field No. Rock Type	1542024 BK-82-029A lava	1542026 BK-82-031 lava	1542027 BK-82-032A lava	1542032 BK-82-033C lava	1542034 BK-82-036A lava	1542036 BK-82-037A lava	1542044 BK-82-040A lava
SiO_2	49.86	50.88	51.23	53.43	51.53	52.75	49.13
TiO_2	0.91	0.93	0.85	1.00	0.74	1.23	0.82
Al_2O_3	15.44	14.90	15.50	15.04	15.77	15.95	16.80
FeO*	9.87	10.55	9.81	10.60	8.85	12.09	9.32
MnO	0.19	0.21	0.17	0.21	0.19	0.20	0.17
MgO	7.51	7.42	7.85	5.37	6.68	6.40	6.01
CaO	12.16	12.04	10.80	10.27	12.76	6.06	16.02
Na_2O	3.91	2.92	3.68	3.97	3.25	4.88	1.64
K_2O	0.08	0.09	0.04	0.04	0.17	0.36	0.04
P_2O_5	0.06	0.05	0.06	0.07	0.06	0.07	0.05
LOI	3.67	1.78	2.25	3.78	3.04	2.44	1.94
Cr	199	71	154	35	78	35	107
Ni	57	44	45	25	36	22	43
V	309	314	301	351	284	464	321
Cu	95	66	70	57	83	58	23
Zn	75	93	81	86	67	105	61
Rb	1	1	1		1	6	4
Ba	29	51	64	59	62	39	50
Sr	96	75	68	101	38	60	159
Ga	12	12	2	15	13	14	18
Nb	0.8	1.0	1.1	0.9	1.5	0.6	4.1
Zr	21	42	33	43	32	32	33
Y	20	30	21	24	20	26	22
Th	0.12		0.09	0.17	0.12	0.13	
La	1.29		1.23		1.39	1.29	
Ce	4.46		3.49		3.70	5.09	
Pr	0.79					0.93	
Nd	4.63		4.72		4.19	5.70	
Sm	1.84		1.95		1.70	2.31	
Eu	0.87		0.89		0.80	0.89	
Gd	2.68		2.60		2.60	3.43	
Tb	0.51					0.66	
Dy	3.65		3.90		2.89	4.58	
Ho	0.84					1.05	
Er	2.24		2.39		1.40	2.85	
Tm	0.32					0.39	
Yb	2.13					2.65	
Lu	0.29					0.36	

Table 2-1. Continued

Sample Field No. Rock Type	1542046 BK-82-041 lava	1542081 BK-82-079B lava	1542089 BK-82-098A lava	1542093 BK-82-100 (silicified) lava	1542096 BK-82-107A lava	1542102 BK-82-113 lava	1542104 BK-82-116A lava
SiO_2	50.85	50.41	51.11	58.46	51.33	51.84	52.84
TiO_2	0.86	0.90	0.53	0.61	0.92	1.31	1.14
Al_2O_3	15.90	16.23	16.81	16.97	16.28	15.08	15.98
FeO*	9.92	10.37	9.08	6.02	10.87	12.90	11.38
MnO	0.20	0.19	0.16	0.10	0.20	0.23	0.21
MgO	8.20	8.70	5.69	4.40	9.28	6.24	6.80
CaO	9.90	10.12	16.38	6.71	7.28	9.51	7.08
Na_2O	3.94	2.79	0.15	6.63	3.75	2.77	4.41
K_2O	0.19	0.24	0.01	0.07	0.03	0.07	0.10
P_2O_5	0.04	0.05	0.08	0.03	0.05	0.06	0.06
LOI	3.37	3.65	3.23	2.14	3.32	2.48	2.31
Cr	166	127	45	55	57	57	78
Ni	49	44	41	34	36	20	32
V	336	306	257	295	278	411	352
Cu	81	83	19	156	54	37	48
Zn	82	85	60	59	59	107	129
Rb	2	2	1		1	1	2
Ba	20	76	46	64	29	63	97
Sr	94	279	105	74	47	86	48
Ga	21	18	1	10	10	15	15
Nb	0.5	3.2	1.4		1.0		
Zr	18	44	22	23	37	49	51
Y	20	29	14	15	28	30	29
Th	0.12		0.34	0.35		0.18	0.13
La	1.07		1.60	1.45		1.76	1.95
Ce	3.80		3.60	3.00		5.68	5.88
Pr	0.68						
Nd	4.23		2.90	2.90		6.82	7.69
Sm	1.66		1.00	1.14		2.79	3.00
Eu	0.71			0.52		1.03	1.39
Gd	2.49		1.39	2.07		4.03	4.28
Tb	0.51						
Dy	3.57		3.50	2.48		4.75	4.92
Ho	0.83						
Er	2.33		1.39	1.76		3.61	3.32
Tm	0.33						
Yb	2.10			1.66		3.51	3.32
Lu	0.30						

Table 2-1. Continued

Sample	1542112	1542114	1542116	1542117	1542118	1542119	1542123
Field No.	BK-82-124C	BK-82-127	BK-82-134	BK-82-136	BK-82-141	BK-82-144A	BK-82-147
Rock Type	lava	lava	lava	breccia	(variolitic) lava	lava	(silicified) lava
SiO_2	53.59	52.73	54.46	57.71	54.81	52.59	54.49
TiO_2	0.91	1.19	0.67	0.63	0.20	0.78	0.63
Al_2O_3	15.62	15.58	15.73	15.30	14.58	16.96	15.84
FeO*	8.94	11.43	7.87	7.02	7.78	9.42	6.88
MnO	0.19	0.21	0.14	0.11	0.13	0.19	0.14
MgO	5.26	5.52	6.46	4.31	8.13	9.29	4.48
CaO	12.01	10.16	10.75	9.47	13.16	6.51	16.92
Na_2O	3.38	3.07	3.70	4.91	1.07	4.18	0.56
K_2O	0.05	0.04	0.17	0.50	0.13	0.05	0.03
P_2O_5	0.05	0.07	0.04	0.03	0.01	0.04	0.03
LOI	1.74	3.48	1.82	1.84	2.43	3.10	2.29
Cr	34		94	209	419	179	147
Ni	30	23	38	60	82	65	49
V	316	382	266	303	253	329	300
Cu	77	38	79	38	31	202	79
Zn	71	103	66	39	58	108	59
Rb			2	9	3		1
Ba	54	71	17	88	17	22	10
Sr	44	33	55	89	97	39	88
Ga	11	14	11	16	18	7	12
Nb			0.4		1.0	0.7	2.1
Zr	35	52	16	23	17	16	29
Y	21	30	17	17	5	18	20
Th	0.67	0.13	0.11	0.16	0.32	0.18	
La	1.45	1.88	0.62	1.26	1.14	1.23	
Ce	4.14	6.43	2.26	2.53	2.50	3.87	
Pr			0.41		0.29	0.65	
Nd	4.76	7.54	2.65	3.38	1.31	3.91	
Sm	1.76	2.88	1.25	1.16	0.32	1.53	
Eu	1.03	1.33	0.39	0.37	0.18	0.62	
Gd	3.10	4.21	1.90	2.11	0.56	2.25	
Tb			0.42		0.10	0.44	
Dy	3.41	4.87	2.95	3.06	0.83	3.12	
Ho			0.69		0.20	0.72	
Er	2.69	3.87	1.94	2.00	0.67	2.03	
Tm			0.27		0.09	0.30	
Yb		3.99	1.83	1.69	0.84	2.05	
Lu			0.27		0.12	0.29	

Table 2-1. Continued

Sample Field No. Rock Type	1542125 BK-82-160A lava	1542127 BK-82-165A lava	1542129 BK-82-166 lava	1542147 BK-82-195 lava	1542149 BK-82-204 (qtz. veins) lava	1542151 BK-82-205 (qtz. veins) lava	1542215 DE-83-182 lava
SiO_2	52.13	52.57	53.36	51.26	57.75	56.04	54.13
TiO_2	0.71	0.64	0.39	0.94	0.93	0.94	0.99
Al_2O_3	15.57	16.46	15.94	15.84	15.20	15.82	14.28
FeO*	8.44	7.68	6.93	9.14	9.08	10.83	9.48
MnO	0.16	0.16	0.15	0.18	0.17	0.18	0.17
MgO	7.06	7.94	5.49	7.62	4.70	4.65	6.91
CaO	13.99	10.34	17.40	11.65	7.67	6.46	8.46
Na_2O	1.78	4.13	0.30	3.01	4.38	4.89	4.80
K_2O	0.11	0.05	0.03	0.31	0.07	0.09	0.72
P_2O_5	0.04	0.03	0.01	0.05	0.06	0.10	0.06
LOI	1.96	2.58	2.54	2.23	2.13	2.76	1.93
Cr	97	261	157	221	18	5	115
Ni	46	82	60	66	17	12	38
V	246	264	202	296	426	439	309
Cu	180	71	182	69	96	105	33
Zn	66	62	50	77	70	95	70
Rb	3	1		6		1	6
Ba	26	32	10	35	39	21	154
Sr	107	81	66	107	68	63	220
Ga	11	11	12	13	11	16	14
Nb	2.1	0.6	0.5	0.6	0.4	2.5	
Zr	32	25	16	36	39	28	40
Y	19	15	10	22	22	21	22
Th		0.17	0.17	0.26	0.31	0.30	0.18
La		1.40	0.88	1.46	2.19	2.60	
Ce		3.50	1.72	3.75	5.54	7.12	
Pr						1.00	
Nd		4.10	1.72	4.27	4.91	5.28	
Sm		1.51	0.91	1.98	1.88	1.78	
Eu		0.31	0.54	0.94	0.94	0.70	
Gd		1.99	0.97	2.81	2.92	2.54	
Tb						0.51	
Dy		2.51	1.40	3.65	3.45	3.60	
Ho						0.87	
Er		1.88	1.40		2.82	2.41	
Tm						0.34	
Yb		1.78	1.18		2.09	2.32	
Lu						0.33	

Table 2-1. Continued

Sample Field No. Rock Type	1542237 DE-83-265 lava (?)	1542249 BK-83-045 lava	1542256 BK-83-101 (qtz. amygdules) lava	1542257 BK-83-105A lava	1542262 BK-83-136A lava	1542263 BK-83-138 lava	1542265 BK-83-164A lava
SiO_2	55.38	51.85	55.77	51.38	52.90	51.14	50.82
TiO_2	0.87	0.93	0.91	0.93	0.85	0.62	0.74
Al_2O_3	15.21	15.40	14.74	15.90	15.95	15.85	15.36
FeO*	9.11	10.57	10.45	9.74	10.18	10.61	9.23
MnO	0.17	0.17	0.22	0.12	0.15	0.17	0.16
MgO	8.05	8.47	5.81	7.81	7.79	7.67	9.35
CaO	7.72	9.54	7.27	11.90	7.65	10.41	11.66
Na_2O	3.29	2.86	4.60	2.09	4.26	2.93	2.47
K_2O	0.13	0.15	0.15	0.05	0.20	0.31	0.17
P_2O_5	0.06	0.05	0.07	0.06	0.06	0.04	0.05
LOI	2.74	3.44	2.35	3.18	2.91	2.66	3.47
Cr	81	92	37	150	98	84	216
Ni	37	41	17	50	33	42	62
V	344	347	342	297	381	335	253
Cu	94	81	59	68	57	72	73
Zn	191	73	86	68	79	86	72
Rb	1	3	2	2	4	7	4
Ba	31	13	33	29	25	62	32
Sr	158	179	24	244	57	156	132
Ga	19	15	9	27	5	18	16
Nb	1.0	0.8	0.9	1.4		0.4	
Zr	27	29	38	36	31	33	28
Y	21	21	19	16	20	18	17
Th	0.28	0.17	0.15	0.21	0.18	0.25	0.15
La	1.91	1.34		1.08	1.62	1.80	1.20
Ce	5.60	4.31		3.00	4.32	4.02	3.36
Pr	0.88	0.77					
Nd	4.75	4.80		3.76	5.07	4.55	3.90
Sm	1.84	1.81		1.50	1.94	1.48	1.41
Eu	0.76	0.74		1.04	1.84	1.01	0.37
Gd	2.57	2.41		2.68	2.92	2.86	2.19
Tb	0.52	0.48				0.00	
Dy	3.82	3.37		2.90	3.67	3.70	3.00
Ho	0.87	0.78					
Er	2.46	2.41		1.93	2.27	1.58	1.90
Tm	0.35	0.34					
Yb	2.43	2.34					
Lu	0.36	0.34					

Table 2-1. Continued

Sample	1542266	1542267	1542285	1543325	1543326	1543328	1543329
Field No.	BK-83-168A	BK-83-187A	BK-83-013D	BK-88-002	BK-88-003	BK-88-005A	BK-88-005S
Rock Type	lava	(qtz. amygdules) lava	(silicified) lava	lava	(variolitic) lava	(variolitic) lava	lava
SiO_2	53.52	62.92	74.06	54.13	56.39	57.53	54.99
TiO_2	0.96	1.22	0.35	0.68	0.90	0.11	0.08
Al_2O_3	16.28	13.44	10.85	13.35	15.56	8.51	8.32
FeO*	10.98	8.86	7.72	8.30	7.82	8.12	9.47
MnO	0.16	0.12	0.04	0.17	0.14	0.18	0.21
MgO	6.21	3.00	1.91	7.07	7.85	15.59	17.86
CaO	9.33	3.57	1.35	12.43	4.78	7.94	7.88
Na_2O	2.42	6.56	3.49	3.74	6.18	0.45	0.18
K_2O	0.07	0.21	0.20	0.07	0.33	1.56	1.00
P_2O_5	0.07	0.09	0.03	0.05	0.05	0.01	0.01
LOI	4.24	1.13	2.31	1.89	3.00	4.68	4.58
Cr	61	22	9	209	308	988	1179
Ni	29	4	1	76	122	205	249
V	300	368	2	248	259	208	234
Cu	51	22	809	49	121	43	48
Zn	94	73	11	40	76	37	47
Rb	1	2	8	1	6	28	17
Ba	4	29	27			48	25
Sr	138	24	44	50	61	73	28
Ga	19	11	11	14	13	6	11
Nb	0.8	1.8	4.1	0.5	0.8	0.9	0.7
Zr	37	46	139	32	39	18	19
Y	22	25	67	17	18	4	3
Th	0.15	0.23		0.13	0.20	0.44	0.40
La	1.31	2.13		0.67	0.89	1.91	1.19
Ce	4.68	6.75		2.22	3.11	3.51	2.42
Pr	0.82	1.13		0.44	0.65	0.41	0.27
Nd	5.00	6.34		2.60	4.00	1.40	1.12
Sm	1.96	2.24		1.22	1.75	0.44	0.32
Eu	1.00	0.79		0.48	0.60	0.13	0.08
Gd	2.81	3.31		1.90	2.46	0.34	0.28
Tb	0.57	0.64		0.40	0.49	0.07	0.06
Dy	3.99	4.45		2.85	3.38	0.53	0.43
Ho	0.91	1.01		0.67	0.76	0.13	0.11
Er	2.58	2.84		1.88	2.20	0.48	0.40
Tm	0.37	0.40		0.28	0.31	0.08	0.07
Yb	2.47	2.69		1.83	2.12	0.59	0.54
Lu	0.35	0.37		0.29	0.32	0.12	0.08

Table 2-1. Continued

Sample	1543334	1543335	1543336	1543337	1543344	1543347	1543348	1543349
Field No.	BK-88-009	BK-88-010	BK-88-011	BK-88-012	BK-88-018	BK-88-021	BK-88-022	BK-88-023
Rock Type	(variolitic) lava	(variolitic) lava	(variolitic) lava	(variolitic) lava	lava	(variolitic) lava	lava	(qtz. amygdules) lava
SiO_2	55.70	59.09	62.86	56.82	50.88	54.69	51.61	61.43
TiO_2	0.13	0.21	0.06	0.10	1.48	0.19	0.78	0.98
Al_2O_3	13.28	12.79	10.15	12.14	15.44	14.37	17.20	13.00
FeO*	9.02	7.38	7.74	8.80	10.21	8.66	10.03	9.29
MnO	0.15	0.09	0.15	0.19	0.21	0.17	0.17	0.18
MgO	12.51	9.39	8.82	10.29	6.62	6.82	7.65	3.71
CaO	6.00	5.55	6.15	7.20	11.28	11.93	8.57	7.31
Na_2O	1.69	5.39	3.85	4.03	3.59	3.06	3.87	3.88
K_2O	1.50	0.10	0.20	0.40	0.15	0.09	0.06	0.15
P_2O_5	0.01	0.01	0.02	0.03	0.14	0.02	0.05	0.07
LOI	4.46	2.62	1.85	2.44	3.42	1.69	3.87	1.68
Cr	527	325	955	838	96	380	174	
Ni	80	73	195	176	30	81	57	
V	260	274	254	264	311	253	284	379
Cu	131	14	56	83	53		104	20
Zn	48	39	38	51	52	26	68	54
Rb	33	1	2	7	3		1	2
Ba	109		12	93		51		
Sr	56	51	71	61	232	195	59	33
Ga	10	10	7	9	18	19	15	14
Nb	1.3	0.9	0.8	0.8	3.2	0.9	0.6	0.9
Zr	20	22	22	20	114	35	33	54
Y	4	5	2	2	36	5	23	25
Th	0.54	0.33	0.24	0.25	0.35	0.5	0.09	0.20
La	1.19	1.30	0.73	0.52	4.22	1.76	0.94	1.82
Ce	2.87	3.07	1.62	1.47	12.52	3.67	3.36	6.09
Pr	0.36	0.41	0.20	0.16	2.08	0.44	0.67	1.10
Nd	1.52	1.79	0.88	0.65	10.82	1.84	3.97	6.02
Sm	0.48	0.58	0.24	0.31	3.72	0.56	1.72	2.30
Eu	0.13	0.16	0.08	0.07	1.44	0.20	0.52	0.69
Gd	0.36	0.57	0.20	0.19	4.78	0.64	2.52	3.01
Tb	0.11	0.11	0.04	0.03	0.95	0.10	0.51	0.60
Dy	0.64	0.87	0.35	0.29	6.18	0.76	3.88	4.18
Ho	0.14	0.20	0.07	0.07	1.38	0.20	0.88	0.97
Er	0.56	0.60	0.27	0.23	3.87	0.65	2.50	2.79
Tm	0.09	0.10	0.05	0.04	0.56	0.11	0.35	0.40
Yb	0.90	0.80	0.41	0.39	3.53	0.67	2.30	2.69
Lu	0.14	0.14	0.07	0.06	0.56	0.15	0.35	0.40

Table 2-1. Concluded

Sample Field No. Rock Type	1543353 BK-88-026 (agglom.) rhyolite	1543354 BK-88-027 lava	1543362 BK-88-034 dacite schist	1543363 BK-88-035 lava	1543365 BK-88-037 (variolitic) lava	1543366 BK-88-038 (variolitic) lava	1542213 DE-83-175 lava (?)	1542216 DE-83-191A agglomerate
SiO_2	76.41	54.97	73.76	54.21	56.55	61.81	57.76	51.19
TiO_2	0.12	0.97	0.29	0.82	0.08	0.16	0.27	1.26
Al_2O_3	11.56	15.17	13.14	15.36	11.44	12.28	15.16	16.00
FeO*	5.29	10.44	4.57	9.50	7.70	6.05	8.49	15.36
MnO	0.04	0.21	0.08	0.13	0.17	0.13	0.13	0.26
MgO	1.09	6.84	1.05	6.93	12.32	7.82	7.87	4.62
CaO	0.37	6.57	0.67	6.72	10.13	5.09	4.96	9.47
Na_2O	5.04	4.71	6.05	4.90	1.48	4.63	3.87	1.69
K_2O	0.03	0.02	0.35	1.36	0.12	0.09	1.46	0.02
P_2O_5	0.04	0.10	0.04	0.08	0.02	1.93	0.03	0.12
LOI	1.75	7.36	1.23	1.75	2.94	1.9	2.77	4.84
Cr	18	23		102	1058	476	139	40
Ni		12		36	305	79	43	4
V	23	406		352	247	238	395	836
Cu	41	102		41	1	131	168	179
Zn	20	35	48	66	98	30	117	146
Rb			2	30	6		18	76
Ba			54	10		9	57	75
Sr	74	81	54	87	150	19	85	263
Ga	11	15	13	13	8	8	11	16
Nb	1.5	1.0	4.6	1.1	1.1	1.0	1.8	2.1
Zr	59	52	162	43	24	16	14	28
Y	9	26	67	25	3	5	6	19
Th	0.85	0.20	0.74	0.13	0.30	0.42	0.62	
La	2.13	1.96	9.74	1.68	1.31	1.76	2.10	
Ce	4.64	5.81	24.13	5.21	2.69	3.31	4.69	
Pr	0.63	1.01	4.22	0.93	0.33	0.41	0.52	
Nd	2.52	5.79	21.50	5.42	1.27	1.64	2.18	
Sm	0.74	2.18	7.15	2.25	0.28	0.51	0.52	
Eu	0.25	0.87	1.55	0.85	0.09	0.14	0.17	
Gd	1.00	3.17	8.83	3.15	0.35	0.48	0.62	
Tb	0.22	0.63	1.75	0.69	0.06	0.11	0.11	
Dy	1.32	4.52	11.95	4.76	0.49	0.90	0.79	
Ho	0.34	1.00	2.56	1.04	0.10	0.21	0.20	
Er	1.17	2.91	7.96	3.31	0.40	0.75	0.71	
Tm	0.19	0.41	1.19	0.43	0.06	0.11	0.11	
Yb	1.36	2.84	8.37	3.01	0.59	0.87	0.88	
Lu	0.27	0.45	1.34	0.45	0.10	0.16	0.14	

Table 2-2. LUSHS BIGHT GROUP DIABASE AND FINE-GRAINED GABBRO*

Sample	1542002	1542003	1542005	1542007	1542008	1542012	1542014
Field No.	BK-82-003A	BK-82-003B	BK-82-007A	BK-82-008C	BK-82-009	BK-82-015B	BK-82-017B
Rock Type	diabase	diabase porphyry	diabase	diabase	diabase	diabase	diabase
SiO_2	53.42	56.27	49.20	52.16	49.12	52.89	54.45
TiO_2	0.89	0.74	0.85	1.01	1.74	0.94	0.63
Al_2O_3	16.29	17.47	15.86	15.59	15.31	15.70	17.75
FeO*	10.69	9.33	9.82	11.24	11.62	10.79	9.86
MnO	0.19	0.18	0.20	0.21	0.21	0.19	0.19
MgO	5.75	3.39	8.55	6.61	7.03	6.69	4.46
CaO	9.22	8.44	13.23	8.44	11.95	10.15	9.01
Na_2O	2.61	2.60	1.70	4.24	2.51	1.97	2.35
K_2O	0.88	1.46	0.53	0.45	0.35	0.59	1.19
P_2O_5	0.06	0.12	0.05	0.06	0.17	0.08	0.11
LOI	2.57	2.43	3.07	1.95	2.03	2.67	2.63
Cr	5	5	151	45	142	48	17
Ni	18	7	50	26	39	29	13
V	331	293	282	345	341	338	293
Cu	77	158	85	64	103	80	143
Zn	87	89	81	95	95	88	94
Rb	13	28	22	9	10	9	22
Ba	121	390	106	68	97	77	294
Sr	286	161	140	212	197	104	316
Ga	16	14	14	17	14	10	17
Nb	6.2	4.1	1.0	1.0	5.1		3.1
Zr	49	67	37	48	110	44	45
Y	24	23	22	28	37	21	19
Th						0.48	
La						2.02	
Ce						5.33	
Pr							
Nd						4.91	
Sm						2.02	
Eu						0.86	
Gd						2.88	
Tb							
Dy						3.84	
Ho							
Er						2.34	
Tm							
Yb							
Lu							

* Field Names based on grain size.

Table 2-2. Continued

Sample Field No. Rock Type	1542015 BK-82-018B porphyritic diabase	1542017 BK-82-019B diabase	1542019 BK-82-020B gabbro	1542021 BK-82-020C diabase	1542022 BK-82-020D diabase	1542023 BK-82-026 gabbro	1542025 BK-82-029B gabbro
SiO_2	54.00	53.06	49.94	51.40	58.35	49.86	50.64
TiO_2	0.58	0.60	0.88	1.62	0.74	0.94	0.94
Al_2O_3	17.00	17.77	15.74	15.32	16.70	15.78	15.52
FeO*	10.40	9.96	10.67	12.07	9.40	9.82	9.68
MnO	0.19	0.18	0.19	0.22	0.19	0.19	0.17
MgO	5.07	4.91	8.04	5.87	3.19	8.48	7.97
CaO	8.94	9.69	11.32	10.05	7.25	12.40	12.28
Na_2O	2.12	2.52	2.70	2.64	2.87	2.34	2.66
K_2O	1.60	1.21	0.44	0.63	1.20	0.14	0.06
P_2O_5	0.10	0.09	0.07	0.17	0.12	0.05	0.07
LOI	2.87	2.54	2.37	2.05	2.44	2.22	2.11
Cr	21	28	90	28	5	246	170
Ni	24	19	42	25	3	59	50
V	304	297	324	385	277	269	284
Cu	121	117	63	76	89	80	69
Zn	88	80	76	100	97	83	70
Rb	27	26	17	13	23	1	2
Ba	489	286	103	137	340	95	64
Sr	258	253	199	162	250	98	116
Ga	14	16	14	15	16	13	12
Nb	3.1	2.1	1.0	4.1	4.1	1.0	1.0
Zr	46	36	36	101	68	42	43
Y	20	19	25	41	28	25	27
Th							
La							
Ce							
Pr							
Nd							
Sm							
Eu							
Gd							
Tb							
Dy							
Ho							
Er							
Tm							
Yb							
Lu							

Table 2-2. Continued

Sample	1542028	1542029	1542031	1542033	1542035	1542037	1542038
Field No.	BK-82-032B	BK-82-033A	BK-82-033B	BK-82-034	BK-82-036B	BK-82-037B	BK-82-038A
Rock Type	diabase	gabbro	gabbro	gabbro	diabase	diabase	gabbro
SiO_2	51.81	51.11	50.08	53.61	52.20	52.79	51.77
TiO_2	1.21	1.26	0.77	0.98	1.11	1.27	1.21
Al_2O_3	15.54	15.58	15.86	15.94	16.55	15.81	15.53
FeO*	11.42	11.88	8.67	10.14	11.29	12.03	12.07
MnO	0.21	0.20	0.16	0.21	0.20	0.22	0.21
MgO	6.28	6.31	9.20	6.29	5.59	5.39	6.42
CaO	11.00	9.48	12.43	8.96	10.25	8.65	8.36
Na_2O	2.37	4.01	2.63	3.56	2.24	2.61	4.27
K_2O	0.06	0.09	0.16	0.25	0.48	1.15	0.16
P_2O_5	0.09	0.08	0.04	0.06	0.09	0.08	0.07
LOI	2.27	2.02	2.58	2.13	2.76	2.54	2.29
Cr	56	5	303	63	48	26	28
Ni	27	20	73	26	21	15	19
V	363	381	256	348	352	397	416
Cu	67	14	94	67	62	57	58
Zn	96	75	68	94	94	105	95
Rb	1	1	2	1	8	25	1
Ba	79	74	74	95	98	165	74
Sr	113	109	155	101	147	138	56
Ga	15	16	12	11	16	15	14
Nb	3.1	2.1	2.1	1.0	0.3	4.1	1.0
Zr	61	60	31	47	57	63	53
Y	33	36	19	27	25	35	32
Th					0.22		
La					2.56		
Ce					7.30		
Pr							
Nd					6.87		
Sm					2.40		
Eu					1.20		
Gd					4.03		
Tb							
Dy					4.69		
Ho							
Er					2.62		
Tm							
Yb							
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542039 BK-82-038B gabbro	1542041 BK-82-038C gabbro	1542042 BK-82-038D gabbro	1542043 BK-82-038E diabase	1542045 BK-82-040C gabbro	1542047 BK-82-042A gabbro	1542048 BK-82-042B gabbro
SiO_2	50.91	52.02	50.71	52.84	50.63	52.79	50.64
TiO_2	1.18	1.08	1.23	1.22	0.91	1.03	0.89
Al_2O_3	15.09	16.43	15.22	15.45	16.01	15.50	15.37
FeO*	12.16	10.75	12.22	11.94	10.92	11.18	10.23
MnO	0.23	0.20	0.21	0.22	0.18	0.18	0.19
MgO	6.72	5.62	6.92	5.48	7.62	6.18	8.34
CaO	9.62	9.35	9.26	7.93	9.84	8.89	11.51
Na_2O	3.60	4.26	4.04	4.75	3.71	3.68	2.41
K_2O	0.25	0.21	0.12	0.10	0.12	0.49	0.39
P_2O_5	0.06	0.07	0.06	0.08	0.05	0.07	0.04
LOI	1.94	2.04	2.25	1.71	2.28	1.92	2.65
Cr	38	48	37	11	103	19	130
Ni	23	23	22	12	36	17	46
V	319	340	430	415	334	354	293
Cu	63	46	53	56	55	60	67
Zn	100	86	88	98	88	96	77
Rb	14	4	2	1	1	8	6
Ba	71	86	66	87	56	86	84
Sr	156	164	117	131	109	130	135
Ga	21	13	17	15	17	17	12
Nb	1.0	1.0	0.0	2.1	1.0	1.0	2.1
Zr	55	54	44	51	36	55	40
Y	33	30	23	31	29	33	25
Th			0.33				
La			1.70				
Ce			4.97				
Pr							
Nd			5.71				
Sm			2.32				
Eu			0.88				
Gd			3.81				
Tb							
Dy			4.66				
Ho							
Er			2.22				
Tm							
Yb							
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542049 BK-82-042C gabbro	1542051 BK-82-042D dyke	1542052 BK-82-045A gabbro	1542053 BK-82-045B dyke	1542054 BK-82-045C gabbro	1542055 BK-82-045D diabase	1542056 BK-82-045F gabbro
SiO_2	50.99	54.29	50.54	48.46	53.33	54.11	49.96
TiO_2	0.98	0.91	0.78	1.70	1.05	1.12	0.83
Al_2O_3	15.56	15.41	15.31	15.19	15.45	15.21	16.36
FeO*	11.57	10.65	10.08	11.89	11.06	11.32	9.74
MnO	0.22	0.19	0.20	0.21	0.20	0.19	0.18
MgO	7.59	6.55	8.27	7.29	5.39	5.97	8.65
CaO	9.53	7.79	12.76	12.44	10.46	8.56	10.67
Na_2O	3.15	3.90	1.89	2.49	2.87	3.32	3.51
K_2O	0.33	0.15	0.14	0.15	0.11	0.12	0.05
P_2O_5	0.08	0.15	0.03	0.16	0.08	0.09	0.04
LOI	2.35	2.27	2.73	2.14	2.61	2.51	2.91
Cr	36	23	152	198	20	10	241
Ni	25	21	52	57	18	18	59
V	338	336	293	373	321	357	298
Cu	88	58	89	78	110	65	89
Zn	89	81	79	91	86	83	81
Rb	7	4	3	5	3	1	4
Ba	91	63	55	94	81	74	66
Sr	116	125	88	147	98	85	81
Ga	14	13	10	18	15	13	10
Nb	2.1	1.0		5.1	2.1	2.1	1.0
Zr	48	43	28	104	56	64	33
Y	32	22	17	37	28	35	24
Th			0.16				
La			1.26				
Ce			3.06				
Pr							
Nd			3.59				
Sm			1.26				
Eu			0.74				
Gd			2.32				
Tb							
Dy			2.85				
Ho							
Er			2.06				
Tm							
Yb							
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542059 BK-82-057A gabbro	1542061 BK-82-057B gabbro	1542082 BK-82-081 gabbro	1542083 BK-82-084 diabase	1542084 BK-82-089A sheeted diabase	1542085 BK-82-089B sheeted diabase	1542086 BK-82-089C sheeted diabase
SiO_2	52.51	53.85	51.84	51.12	50.99	53.91	52.78
TiO_2	0.41	0.73	0.83	0.95	1.22	1.25	1.19
Al_2O_3	12.49	15.54	14.78	15.53	15.25	15.26	15.71
FeO*	9.79	12.33	10.72	10.82	12.46	11.55	11.78
MnO	0.19	0.21	0.20	0.19	0.24	0.21	0.20
MgO	10.05	4.88	8.81	8.06	5.95	4.20	5.87
CaO	11.62	8.63	10.37	9.62	10.82	13.41	10.15
Na_2O	2.06	2.75	2.05	3.00	2.88	0.11	2.21
K_2O	0.83	0.97	0.35	0.66	0.12	0.01	0.02
P_2O_5	0.05	0.10	0.05	0.05	0.07	0.09	0.08
LOI	5.46	3.01	3.20	2.00	2.93	2.64	2.83
Cr	379	14	86	98	5	5	18
Ni	49	18	34	39	18	9	19
V	283	528	305	336	392	368	367
Cu	73	188	15	79	42	25	52
Zn	70	105	73	84	139	137	164
Rb	17	16	6	15			
Ba	120	359	87	101	75	65	68
Sr	92	246	128	122	100	123	119
Ga	7	16	13	12	12	16	13
Nb	3.2	2.1	3.2	3.1	50	54	52
Zr	25	37	42	39	28	24	23
Y	9	19	30	28	0.22	0.28	0.20
Th							
					1.80	2.25	2.15
La					5.52	6.75	6.67
Ce							
Pr					5.94	6.53	6.13
Nd					2.44	2.36	2.48
Sm							1.03
Eu					3.92	3.53	3.66
Gd							
Tb					4.88	4.18	4.09
Dy							
Ho							2.15
Er							
Tm							
Yb							
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542087 BK-82-091 diabase	1542094 BK-82-102 diabase	1542095 BK-82-105 diabase	1542097 BK-82-107B diabase	1542098 BK-82-108C diabase	1542099 BK-82-108D diabase	1542103 BK-82-114 gabbro
SiO_2	51.48	50.29	56.46	52.43	51.78	49.29	51.76
TiO_2	0.71	0.92	0.20	1.00	0.91	1.15	1.27
Al_2O_3	15.51	17.04	11.41	15.12	15.58	16.45	14.79
FeO*	8.80	11.03	7.56	10.72	10.07	9.98	12.15
MnO	0.19	0.19	0.17	0.19	0.18	0.20	0.22
MgO	8.37	8.26	9.28	7.77	8.10	8.36	5.32
CaO	11.23	9.46	13.99	8.97	10.28	12.32	12.03
Na_2O	3.48	2.71	0.89	3.72	2.46	1.75	2.33
K_2O	0.17	0.05	0.03	0.03	0.60	0.43	0.06
P_2O_5	0.07	0.04	0.02	0.06	0.04	0.07	0.06
LOI	2.64	3.47	3.57	2.81	3.67	2.40	2.27
Cr	292	117	500	154	111	246	43
Ni	73	45	123	42	38	270	18
V	275	356	227	336	317	12	376
Cu	74	65	65	73	76	144	52
Zn	73	87	57	87	79	126	94
Rb	3	3	1		13	9	3
Ba	85	58	52	12	97	1	72
Sr	133	143	141	55	69	122	119
Ga	9	15	7	12	15	33	20
Nb	1.0	3.1	5.2	0.8	0.4	0.8	1.0
Zr	27	37	17	24	32	60	51
Y	22	27	6	26	20	25	35
Th				0.15	0.24	0.16	
La				1.41	1.55	2.76	
Ce				4.83	3.77	8.08	
Pr				0.86			
Nd				5.19	4.43	8.61	
Sm				2.04	1.99	3.19	
Eu				0.86	0.82	1.17	
Gd				3.03	2.99	4.46	
Tb				0.61			
Dy				4.38	3.65	5.21	
Ho				1.00			
Er				2.81	1.88	2.34	
Tm				0.39			
Yb				2.73		1.80	
Lu				0.37			

Table 2-2. Continued

Sample Field No. Rock Type	1542105 BK-82-116B gabbro	1542106 BK-82-118A gabbro	1542108 BK-82-121 gabbro	1542109 BK-82-124A gabbro	1542111 BK-82-124B gabbro	1542113 BK-82-126 gabbro	1542115 BK-82-131 gabbro
SiO_2	51.00	50.28	50.05	50.11	48.40	50.53	52.49
TiO_2	1.04	1.03	1.04	0.84	2.27	0.97	1.21
Al_2O_3	16.08	15.67	16.43	16.29	15.40	15.19	15.23
FeO*	10.09	9.90	11.53	9.56	12.79	10.16	11.91
MnO	0.20	0.19	0.21	0.19	0.22	0.20	0.20
MgO	7.43	7.96	7.97	8.10	6.02	8.01	5.15
CaO	11.60	12.54	9.77	12.25	10.92	12.65	9.93
Na_2O	2.10	2.17	2.81	2.27	3.11	2.09	3.76
K_2O	0.40	0.21	0.13	0.35	0.51	0.17	0.05
P_2O_5	0.06	0.05	0.06	0.05	0.36	0.04	0.06
LOI	2.49	3.07	2.54	2.03	1.78	2.27	1.96
Cr	122	228	64	142	21	109	22
Ni	42	61	37	49	29	48	15
V	305	285	331	274	359	296	413
Cu	79	78	61	77	74	81	38
Zn	87	82	95	77	107	78	88
Rb	7	8	2	6	14	3	1
Ba	93	100	69	87	196	74	83
Sr	125	132	98	112	320	100	65
Ga	19	11	13	33	18	16	9
Nb	3.1	1.0		3.1	16.7	3.1	1.0
Zr	48	44	44	43	189	35	54
Y	28	24	25	32	41	22	35
Th			0.24			0.25	
La			2.65			1.28	
Ce			7.00			3.20	
Pr							
Nd			8.91			3.95	
Sm			3.08			1.38	
Eu			1.70			0.83	
Gd			5.20			2.78	
Tb							
Dy			5.30			3.63	
Ho							
Er			2.22			2.67	
Tm							
Yb			1.80			2.56	
Lu							

Table 2-2. Continued

Sample	1542121	1542122	1542124	1542126	1542128	1542141	1542142
Field No.	BK-82-144B	BK-82-144C	BK-82-157	BK-82-160B	BK-82-165B	BK-82-187A	BK-82-187B
Rock Type	gabbro	gabbro	porphyritic diabase	diabase	gabbro	sheeted diabase	sheeted diabase
SiO_2	52.79	52.40	55.68	48.73	50.66	54.22	54.13
TiO_2	1.15	1.14	0.65	1.62	0.92	0.45	0.42
Al_2O_3	15.60	15.48	15.42	15.53	17.04	16.54	16.27
FeO*	12.01	11.86	10.38	10.84	9.23	8.65	8.46
MnO	0.21	0.21	0.20	0.20	0.17	0.15	0.14
MgO	5.62	5.84	5.01	7.88	7.08	6.89	6.56
CaO	9.17	9.42	9.69	12.30	11.59	10.36	11.82
Na_2O	3.30	3.34	2.10	2.27	3.21	2.65	2.14
K_2O	0.07	0.25	0.77	0.49	0.04	0.06	0.03
P_2O_5	0.07	0.07	0.10	0.15	0.05	0.03	0.03
LOI	2.22	2.09	2.02	2.19	2.47	2.36	2.25
Cr	23	19	58	236	134	68	70
Ni	20	20	30	61	54	45	42
V	375	402	361	300	279	280	273
Cu	64	48	155	100	91	20	24
Zn	93	97	98	87	76	67	62
Rb	1	6	16	10	1		1
Ba	42	70	318	124	29	10	21
Sr	99	113	261	191	60	63	66
Ga	14	17	11	11	11	12	11
Nb	1.0	1.0	1.0	4.2	2.1	0.5	
Zr	53	49	36	97	46	21	19
Y	32	35	20	31	28	11	8
Th						0.58	0.41
La						1.62	1.28
Ce						2.58	1.82
Pr							
Nd						2.04	1.60
Sm						0.36	0.32
Eu						0.54	0.50
Gd						1.18	1.28
Tb							
Dy						1.94	1.50
Ho							
Er						1.50	1.06
Tm							
Yb						1.50	0.74
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542143 BK-82-187C sheeted diabase	1542144 BK-82-187D sheeted diabase	1542145 BK-82-187E sheeted diabase	1542146 BK-82-187F sheeted diabase	1542148 BK-82-198 gabbro	1542204 DE-83-127B pyroxenite	1542205 DE-83-157 diabase
SiO_2	51.65	53.52	53.13	51.27	51.49	45.10	52.54
TiO_2	0.69	0.67	0.31	1.39	1.14	0.07	0.88
Al_2O_3	16.29	16.65	17.49	16.65	15.30	2.81	15.76
FeO*	8.44	8.92	7.04	8.68	11.50	8.89	10.49
MnO	0.16	0.20	0.18	0.18	0.21	0.14	0.19
MgO	8.46	7.55	8.83	8.97	6.63	40.35	7.85
CaO	11.06	9.35	8.66	7.06	10.80	2.55	8.08
Na_2O	3.06	3.04	3.83	4.45	2.66	0.07	4.09
K_2O	0.15	0.05	0.52	0.99	0.22	0.01	0.06
P_2O_5	0.03	0.05	0.02	0.36	0.66	0.01	0.05
LOI	2.39	3.76	2.80	2.88	2.24	10.25	4.10
Cr	244	111	118	366	44	3538	102
Ni	69	52	50	173	28	1338	35
V	247	266	254	212	351	101	408
Cu	46	52	12	55	55	9	69
Zn	67	89	73	94	92	45	135
Rb			5	14	8		2
Ba	31	10	53	486	39	3	51
Sr	131	150	131	678	108	9	99
Ga	9	14	12	18	18	3	21
Nb		1.0	1.3	15.8	1.0	3.3	0.0
Zr	23	37	13	151	54		32
Y	14	4	7	25	35	6	19
Th	0.23	0.42	0.20				0.21
La	1.16	2.74	0.90				1.37
Ce	2.31	5.49	1.06				3.15
Pr							
Nd	2.94	4.71	1.28				4.20
Sm	1.26	1.32	0.20				1.47
Eu	0.69	0.84					1.16
Gd	1.68	2.52	1.01				3.05
Tb							
Dy	2.42	3.73	1.28				3.36
Ho							
Er	1.68	1.98	1.01				2.31
Tm							
Yb	1.16	2.08					
Lu							

Table 2-2. Continued

Sample	1542206	1542207	1542208	1542211	1542214	1542217	1542218
Field No.	DE-83-159	DE-83-162	DE-83-168	DE-83-171	DE-83-178	DE-83-191B	DE-83-212
Rock Type	diabase	diabase	(variolitic) diabase	diabase	gabbro	gabbro	gabbro
SiO_2	57.01	58.07	57.28	52.71	52.72	61.18	50.95
TiO_2	0.17	0.17	0.20	0.89	0.83	0.78	2.42
Al_2O_3	9.26	12.30	13.76	14.66	14.74	16.54	13.97
FeO*	7.96	7.71	8.65	8.90	9.37	5.65	14.67
MnO	0.16	0.13	0.14	0.17	0.19	0.12	0.24
MgO	11.30	10.69	8.76	7.76	8.24	6.79	5.03
CaO	12.01	6.31	6.06	10.01	9.29	2.88	8.47
Na_2O	2.01	4.50	5.02	4.72	4.09	5.55	3.69
K_2O	0.10	0.09	0.11	0.15	0.45	0.24	0.28
P_2O_5	0.03	0.03	0.02	0.04	0.07	0.26	0.28
LOI	3.94	2.70	2.49	4.82	1.65	4.42	2.32
Cr	1349	715	59	1759	158	257	31
Ni	337	114	87	43	52	137	14
V	229	293	704	367	303	198	433
Cu	18	75	50	14	76	27	58
Zn	50	66	76	38	86	78	127
Rb	1				19	1	14
Ba	23	22	40	48	48	148	126
Sr	191	88	96	135	117	396	189
Ga	8	8	14	2	14	19	24
Nb	1.2	4.2	1.2	3.2	2.0	5.3	13.4
Zr	17	8	22	24	26	132	178
Y	3	6	1	24	27	25	48
Th	0.27		0.57				
La	1.58		2.16				
Ce	3.02		3.49				
Pr	0.32						
Nd	1.30		1.85				
Sm	0.30		0.62				
Eu	0.16		0.31				
Gd	0.37		0.62				
Tb	0.06						
Dy	0.48		0.62				
Ho	0.11						
Er	0.34		0.51				
Tm	0.05						
Yb	0.41						
Lu	0.07						

Table 2-2. Continued

Sample Field No. Rock Type	1542219 DE-83-220 gabbro	1542221 DE-83-222 gabbro	1542222 DE-83-223 gabbro	1542223 DE-83-232 gabbro	1542224 DE-83-237 gabbro	1542225 DE-83-239 gabbro	1542235 DE-83-259 gabbro
SiO_2	52.55	51.91	51.94	51.74	53.01	49.36	53.09
TiO_2	0.92	0.86	1.02	2.31	1.15	0.93	1.26
Al_2O_3	14.62	15.03	15.19	14.61	15.62	16.28	14.78
FeO*	10.16	9.45	9.50	14.40	12.09	9.49	12.35
MnO	0.19	0.19	0.19	0.23	0.21	0.18	0.21
MgO	7.69	8.45	7.80	4.70	6.57	9.56	6.17
CaO	9.29	9.69	11.46	6.48	7.44	11.53	7.07
Na_2O	4.06	2.71	2.48	4.99	3.77	2.42	4.81
K_2O	0.45	1.64	0.36	0.29	0.07	0.19	0.19
P_2O_5	0.06	0.05	0.07	0.25	0.08	0.06	0.07
LOI	2.35	2.66	3.54	2.31	3.45	2.67	2.51
Cr	84	151	157	31	35	416	
Ni	38	46	52	8	14	150	21
V	310	292	285	510	398	268	360
Cu	74	42	54	37	27	54	48
Zn	92	80	81	126	103	81	87
Rb		22	5	15	5	4	
Ba	57	102	78	178	42	56	44
Sr	125	110	198	180	90	124	125
Ga	13	15	16	20	16	18	16
Nb	4.1	3.1	4.1	10.3	6.2	1.4	5.2
Zr	17	16	32	128	37	41	39
Y	27	30	35	53	40	20	49
Th						0.31	
La						1.91	
Ce						4.99	
Pr							
Nd						5.31	
Sm						2.02	
Eu						0.84	
Gd						3.40	
Tb							
Dy						3.61	
Ho							
Er						2.23	
Tm							
Yb							
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542236 DE-83-262 diabase	1542239 DE-83-268 pyroxenite	1542243 DE-83-301B diabase	1542244 DE-83-314 gabbro	1542245 DE-83-315 gabbro	1542246 BK-83-029 gabbro	1542247 BK-83-039 gabbro
SiO_2	49.62	42.49	56.08	55.18	56.41	51.51	53.95
TiO_2	0.83	0.20	0.92	1.32	1.31	0.80	0.89
Al_2O_3	14.56	4.52	15.99	15.42	15.08	14.59	15.26
FeO*	9.72	11.34	11.17	11.86	12.13	9.87	9.93
MnO	0.20	0.16	0.17	0.21	0.20	0.19	0.18
MgO	11.36	37.99	5.54	5.42	4.26	9.59	6.90
CaO	10.45	3.22	5.77	6.63	6.50	10.86	8.36
Na_2O	2.63	0.03	4.04	3.78	3.92	2.20	4.39
K_2O	0.58	0.01	0.26	0.08	0.10	0.34	0.06
P_2O_5	0.04	0.02	0.07	0.09	0.09	0.05	0.07
LOI	3.24	9.84	2.87	3.23	2.22	2.75	3.88
Cr	510	2225	31	60	28	259	72
Ni	102	1086	17	15	8	74	28
V	442	100	366	433	457	303	344
Cu	70	14	100	102	39	71	51
Zn	80	74	98	70	102	81	105
Rb	9	1	3	7		17	2
Ba	159	19	64	50	49	69	16
Sr	181	8	92	103	107	81	41
Ga		2	16	16	17	15	13
Nb	1.1	1.1	1.2	2.1	5.2		
Zr	34		56	58	59	17	38
Y	19	7	21	42	49	27	17
Th	0.23		0.46				0.36
La	1.40		2.14				1.53
Ce	3.57		5.57				4.15
Pr							
Nd	4.55		5.03				4.15
Sm	2.16		1.82				1.31
Eu	1.19		0.94				1.53
Gd	3.03		2.46				2.62
Tb							0.00
Dy	3.35		3.53				3.17
Ho							0.00
Er	2.16		2.46				1.97
Tm							0.00
Yb	1.84		2.46				0.00
Lu							0.00

Table 2-2. Continued

Sample Field No. Rock Type	1542248 BK-83-043B gabbro	1542251 BK-83-050 gabbro	1542252 BK-83-051 gabbro	1542253 BK-83-062 gabbro	1542254 BK-83-067 gabbro	1542255 BK-83-093 gabbro	1542258 BK-83-105B gabbro
SiO_2	51.97	49.94	50.84	51.94	60.13	51.90	52.24
TiO_2	0.93	0.93	0.89	0.92	0.23	0.75	0.80
Al_2O_3	15.62	16.07	15.41	15.39	15.14	15.71	15.93
FeO*	10.20	9.55	9.19	10.49	7.50	9.30	10.32
MnO	0.19	0.18	0.17	0.19	0.16	0.18	0.16
MgO	7.09	8.27	7.95	6.88	4.71	8.36	7.99
CaO	10.30	12.44	12.98	11.94	9.10	9.63	10.47
Na_2O	3.52	2.44	2.50	2.10	3.00	4.01	1.61
K_2O	0.12	0.14	0.03	0.10	0.01	0.11	0.43
P_2O_5	0.06	0.04	0.04	0.05	0.03	0.04	0.04
LOI	2.70	2.61	2.39	2.10	4.38	2.92	3.46
Cr	74	237	207	108	127	129	84
Ni	35	59	53	37	40	51	39
V	297	275	273	321	234	287	311
Cu	71	87	71	44	66	80	66
Zn	91	77	73	81	74	79	84
Rb	7	10		1		2	10
Ba	34	58	24	40	28	30	74
Sr	148	117	97	88	102	185	123
Ga	16	14	13	14	13	14	20
Nb	1.0	0.0	0.6	1.0	1.2	3.1	4.2
Zr	30	25	36	38	34	24	19
Y	28	33	21	23	6	28	29
Th			0.21	0.16	0.93		
La			1.38	1.26	2.32		
Ce			4.64	4.08	4.53		
Pr							
Nd			5.59	5.44	2.54		
Sm			1.90	2.50	0.60		
Eu			1.16	1.04	0.50		
Gd			2.96	3.34	0.75		
Tb							
Dy			3.58	3.86	0.98		
Ho							
Er			2.42	2.72	0.79		
Tm							
Yb			2.00	2.50	0.73		
Lu							

Table 2-2. Continued

Sample	1542261	1542264	1542268	1542269	1542283	1542284	1542286
Field No.	BK-83-125	BK-83-144	BK-83-187B	BK-83-274	BK-83-005	BK-83-009	BK-83-025
Rock Type	gabbro	gabbro	diabase	sheeted diabase	gabbro	gabbro	diabase
SiO_2	51.49	51.34	62.89	55.81	53.76	55.00	51.69
TiO_2	1.12	0.84	0.36	0.18	1.12	0.82	1.13
Al_2O_3	15.68	15.45	15.26	15.09	15.26	14.88	16.63
FeO*	12.02	9.87	8.05	8.69	11.47	9.03	10.40
MnO	0.21	0.16	0.13	0.15	0.20	0.12	0.18
MgO	6.75	7.62	3.47	7.41	6.17	5.37	5.85
CaO	9.94	12.54	4.35	10.64	8.14	11.05	11.57
Na_2O	2.66	2.08	4.82	1.76	3.62	3.39	2.31
K_2O	0.06	0.03	0.62	0.23	0.19	0.29	0.20
P_2O_5	0.06	0.06	0.04	0.02	0.08	0.05	0.05
LOI	3.23	2.60	1.93	1.01	2.26	2.03	2.63
Cr	63	103	57	147	54	94	104
Ni	27	42	16	72	24	35	37
V	365	280	300	317	348	325	319
Cu	35	78	103	4	60	55	75
Zn	100	83	75	21	189	64	86
Rb			4	6	7	6	18
Ba	58	24	105	75	75	29	102
Sr	169	236	72	77	119	86	137
Ga	19	15	14	9	14	16	19
Nb	1.0	0.3		2.1	2.1	1.0	4.1
Zr	45	32	25	19	40	16	44
Y	26	17	14	5	34	31	36
Th	0.27	0.17		0.56			
La	1.65	1.26					
Ce	5.17	3.69					
Pr							
Nd	6.05	4.64					
Sm	2.31	0.00					
Eu	1.10	0.80					
Gd	3.74	2.64					
Tb							
Dy	4.51	2.74					
Ho							
Er	3.08	2.10					
Tm							
Yb	2.20	1.80					
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542289 DE-83-334B diabase	1542293 DE-83-359 diabase	1542294 DE-83-362 gabbro	1542295 DE-83-373 gabbro	1542296 DE-83-378 gabbro	1542297 DE-83-389 gabbro	1542298 DE-83-392 diabase
SiO_2	49.95	52.52	51.62	50.30	50.50	54.08	60.20
TiO_2	0.47	1.37	0.61	1.09	0.82	0.97	0.50
Al_2O_3	8.84	15.84	15.52	15.05	15.52	16.81	16.04
FeO*	8.95	9.97	9.33	11.03	9.62	11.27	9.64
MnO	0.18	0.18	0.17	0.19	0.17	0.20	0.15
MgO	17.40	6.05	8.38	8.43	8.10	4.24	3.73
CaO	12.31	9.56	11.83	11.33	13.17	8.77	5.02
Na_2O	0.68	3.59	2.17	2.27	1.92	2.55	4.68
K_2O	1.15	0.77	0.34	0.26	0.13	0.89	0.02
P_2O_5	0.06	0.15	0.02	0.06	0.03	0.22	0.02
LOI	2.67	2.06	2.53	2.60	2.82	3.13	2.38
Cr	994	52	169	128	215	52	33
Ni	195	33	48	51	64	13	16
V	213	269	245	327	266	397	435
Cu	107	68	87	45	79	159	239
Zn	99	89	70	79	67	101	80
Rb	69	13	15	13	3	9	
Ba	279	180	34	52	28	994	37
Sr	89	132	125	133	82	300	91
Ga	8	17	15	16	17	15	17
Nb	2.1	9.2		3.1	0.5		1.0
Zr	10	133	11	36	33	52	10
Y	15	51	24	39	20	30	10
Th					0.10		0.50
La					1.40		2.29
Ce					3.64		4.81
Pr							
Nd					4.93		2.62
Sm					2.04		0.84
Eu					0.82		0.56
Gd					2.89		0.99
Tb					0.00		
Dy					3.54		1.16
Ho							
Er					2.25		0.88
Tm					0.00		
Yb					2.04		0.79
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542299 DE-83-395 diabase	1542301 DE-83-398B diabase	1542302 DE-83-427 gabbro	1542303 DE-83-432 gabbro	1542304 DE-83-435 gabbro	1542305 DE-83-444 gabbro	1542306 DE-83-445 gabbro
SiO_2	61.05	51.17	55.74	50.77	50.27	50.95	52.44
TiO_2	1.27	0.91	0.61	0.86	0.83	0.67	0.83
Al_2O_3	14.41	15.20	19.13	15.37	15.81	14.66	15.58
FeO*	10.01	9.45	8.88	8.75	10.65	9.19	10.08
MnO	0.13	0.17	0.17	0.16	0.18	0.17	0.17
MgO	3.04	8.26	3.65	7.28	9.14	10.20	7.63
CaO	3.66	11.61	7.50	12.55	9.36	12.32	9.55
Na_2O	6.34	3.03	4.06	4.11	3.51	1.73	3.60
K_2O	0.01	0.15	0.11	0.12	0.22	0.08	0.08
P_2O_5	0.08	0.05	0.16	0.03	0.04	0.02	0.03
LOI	1.64	3.61	3.05	5.24	3.37	2.59	2.26
Cr	29	191	12	354	195	272	39
Ni	6	58	6	106	50	83	29
V	414	284	182	242	320	241	301
Cu	75	64	21	278	69	100	136
Zn	82	72	80	89	83	70	82
Rb		6	3	5	6	5	6
Ba	52	34	88	50	38	31	49
Sr	90	68	551	43	224	116	92
Ga	14	15	20	15	13	11	13
Nb	5.2	4.2	4.2	5.3		1.0	4.1
Zr	56	23	66	23	23	13	20
Y	42	33	26	26	33	23	31
Th		0.23		0.50			0.15
La		1.54					
Ce		4.63					
Pr							
Nd		5.28					
Sm		2.37					
Eu		1.40					
Gd		3.02					
Tb							
Dy		3.77					
Ho							
Er		2.69					
Tm							
Yb		2.04					
Lu							

Table 2-2. Continued

Sample Field No. Rock Type	1542307 DE-83-447A sheeted diabase	1542308 DE-83-447B sheeted diabase	1542309 DE-83-480 gabbro	1542313 BK-83-417 gabbro	1543327 BK-88-004 diabase	1543331 BK-88-006 diabase	1543332 BK-88-007 diabase	1543333 BK-88-008 diabase
SiO_2	59.68	59.96	50.61	52.17	54.88	52.71	58.55	53.66
TiO_2	0.31	0.40	1.92	0.71	0.67	0.44	0.27	0.64
Al_2O_3	16.35	15.58	14.77	15.99	15.74	13.65	15.37	18.95
FeO*	8.48	9.08	11.95	9.86	8.69	10.06	8.41	9.01
MnO	0.14	0.14	0.21	0.18	0.13	0.17	0.11	0.15
MgO	4.03	3.58	6.57	7.13	6.53	10.56	7.30	6.84
CaO	6.57	5.89	10.35	10.89	8.06	8.47	6.61	5.11
Na_2O	4.30	5.12	3.15	2.46	4.96	3.41	2.94	4.64
K_2O	0.11	0.22	0.29	0.58	0.29	0.47	0.41	0.70
P_2O_5	0.02	0.02	0.18	0.03	0.05	0.06	0.02	0.30
LOI	2.23	1.79	2.10	2.41	2.51	3.6	3.53	4.18
Cr	65	36	88	54	226	496	46	2
Ni	25	16	36	32	60	106	29	
V	284	329	339	298	292	348	278	227
Cu	197	108	56	73		76	96	16
Zn	80	79	115	79	45	56	47	76
Rb		3	12	11	4	3	8	10
Ba	29	85	118	50		24	19	68
Sr	60	116	190	140	165	650	211	175
Ga	14	14	17	18	13	14	14	15
Nb	3.1		6.1	0.8	0.7	1.3	0.6	1.4
Zr	11	14	126	29	39	44	33	62
Y	11	12	48	18	18	11	5	19
Th	0.66	0.48		0.14	0.22	1.03	0.41	2.52
La					1.41	5.07	1.75	12.73
Ce					3.85	10.25	3.75	26.04
Pr					0.64	1.33	0.49	3.51
Nd					3.66	5.94	2.01	13.96
Sm					1.49	1.56	0.62	3.34
Eu					0.63	0.54	0.23	1.03
Gd					2.15	1.59	0.71	3.18
Tb					0.44	0.31	0.14	0.55
Dy					3.18	2.05	0.94	3.67
Ho					0.72	0.46	0.22	0.83
Er					2.01	1.42	0.71	2.35
Tm					0.29	0.19	0.11	0.32
Yb					1.91	1.32	0.78	2.37
Lu					0.29	0.22	0.13	0.38

Table 2-2. Concluded

Sample Field No. Rock Type	1543338 BK-88-013 diabase	1543345 BK-88-019 sheeted diabase	1543346 BK-88-020 sheeted diabase	1543351 BK-88-024 diabase	1543352 BK-88-025 diabase (cut by 3351)	1543359 BK-88-032 felsite dyke (epidosite?)	1543361 BK-88-033 diabase
SiO_2	52.25	60.11	56.96	62.15	57.63	70.46	60.69
TiO_2	0.61	0.23	1.30	0.84	0.93	0.25	0.21
Al_2O_3	12.51	15.37	14.03	11.77	15.25	11.88	15.87
FeO*	10.07	7.66	11.74	8.63	12.23	5.64	8.29
MnO	0.18	0.14	0.19	0.12	0.17	0.06	0.13
MgO	10.34	6.22	4.89	2.48	4.48	0.06	3.18
CaO	10.15	5.35	6.49	13.35	4.31	11.28	7.60
Na_2O	2.54	4.82	4.17	0.47	4.39	0.32	3.90
K_2O	1.19	0.07	0.13	0.11	0.54	0.01	0.10
P_2O_5	0.16	0.03	0.10	0.07	0.08	0.03	0.02
LOI	3.48	2.68	2.16	1.41	3.01	1.2	2.2
Cr	533	176		48			31
Ni	90	65					11
V	351	232	435	304	448	1	286
Cu	47	7	49	67			105
Zn	56	43	50	20	72		50
Rb	43		1	2	10	1	1
Ba	91	20					9
Sr	493	67	71	365	144	533	59
Ga	13	11	15	19	16	30	14
Nb	1.4	1.1	1.6	1.0	1.4	2.6	1.0
Zr	51	43	58	57	50	146	47
Y	14	9	30	22	19	43	7
Th	2.20	0.97	0.24	0.16	0.53	0.51	0.50
La	7.57	3.06	2.45	1.82	2.53	4.32	2.09
Ce	15.54	6.25	7.44	5.31	6.36	12.20	4.51
Pr	2.09	0.76	1.29	0.89	1.01	2.07	0.57
Nd	9.08	3.44	6.97	4.74	5.22	10.55	2.46
Sm	2.49	0.93	2.71	1.78	1.94	3.96	0.73
Eu	0.74	0.26	1.01	0.93	0.73	1.40	0.32
Gd	2.32	0.98	3.66	2.47	2.27	5.26	0.82
Tb	0.39	0.18	0.74	0.49	0.47	1.11	0.18
Dy	2.62	1.44	5.12	3.56	3.32	7.90	1.23
Ho	0.56	0.34	1.15	0.78	0.75	1.76	0.27
Er	1.53	1.09	3.38	2.19	2.24	5.44	0.84
Tm	0.23	0.19	0.51	0.31	0.36	0.81	0.13
Yb	1.44	1.35	3.36	2.15	2.25	5.43	1.02
Lu	0.22	0.22	0.50	0.32	0.35	0.80	0.18

Table 2-3. CUTWELL, CATHERS POND AND WESTERN ARM (WAG) GROUPS

Sample	1542067	1542068	1542069	1542071	1542078	1542132	1542133
Field No.	BK-82-067A	BK-82-067B	BK-82-068	BK-82-069	BK-82-078A	BK-82-171	BK-82-172
Rock Type	diabase	diabase	diabase	breccia	lava	breccia	breccia
GROUP	CUTWELL	CUTWELL	CUTWELL	CUTWELL	CUTWELL	CUTWELL	CUTWELL
SiO_2	51.67	59.53	54.32	51.71	51.60	54.77	53.27
TiO_2	1.76	0.58	0.77	0.76	1.02	0.94	0.79
Al_2O_3	17.06	16.17	19.99	20.15	15.99	17.33	13.48
FeO*	8.84	7.90	7.57	9.05	11.63	9.56	6.39
MnO	0.13	0.17	0.14	0.19	0.20	0.14	0.21
MgO	8.03	3.32	2.83	3.11	7.79	4.58	4.68
CaO	8.34	9.00	8.85	12.29	7.96	8.50	17.23
Na_2O	2.74	2.62	4.91	2.16	3.70	3.53	3.51
K_2O	1.11	0.60	0.45	0.41	0.03	0.54	0.31
P_2O_5	0.31	0.11	0.17	0.16	0.08	0.13	0.12
					7.93	3.76	9.01
LOI	0.25	3.42	3.70	4.07			
					100	90	208
Cr	267	5	16	5	45	40	33
Ni	112	6	5	6	286	323	241
V	216	203	359	312	69	42	45
Cu	43	62	93	83	117	97	91
Zn	78	83	99	88			
						7	8
Rb	26	17	10	5	208	260	82
Ba	201	380	184	248	61	299	231
Sr	171	463	210	403	8	14	9
Ga	15	14	14	14			
						1.1	1.1
Nb	6.7	2.1	1.0	2.1	41	78	52
Zr	207	67	39	42	21	25	22
Y	31	24	23	21	0.16		
Th							
					1.42		
La					3.48		
Ce							
Pr					6.59		
Nd					2.40		
Sm					0.56		
Eu					4.44		
Gd							
Tb					4.80		
Dy							
Ho					2.16		
Er							
Tm							
Yb							
Lu							

Table 2-3. Continued

Sample	1542134	1542135	1542136	1542139	1542276	1542277	1542278
Field No.	BK-82-174	BK-82-175	BK-82-178	BK-82-184	BK-83-312	BK-83-358B	BK-83-360
Rock Type	breccia	lava	lava	lava	lava	lava	lava
GROUP	CUTWELL	CUTWELL	CUTWELL	CUTWELL	CUTWELL	CUTWELL	CUTWELL
SiO_2	53.40	51.43	48.13	54.73	51.41	53.72	52.18
TiO_2	0.77	2.11	2.14	1.57	1.85	2.84	2.06
Al_2O_3	16.86	14.90	14.93	15.71	14.67	13.96	14.70
FeO*	8.94	11.85	11.98	12.42	10.56	13.53	10.94
MnO	0.17	0.21	0.25	0.21	0.21	0.21	0.20
MgO	4.88	5.51	7.30	4.67	6.19	4.31	5.72
CaO	10.08	9.67	11.71	7.06	10.60	6.68	9.38
Na_2O	3.83	3.86	3.23	2.97	4.15	4.38	4.46
K_2O	0.89	0.17	0.13	0.54	0.19	0.05	0.14
P_2O_5	0.18	0.28	0.21	0.12	0.18	0.32	0.22
LOI	4.43	1.99	1.83	2.80	2.35	3.67	2.58
Cr	39	24	117	5	55	24	36
Ni	22	19	39	8	16	3	11
V	270	371	336	357	343	449	338
Cu	69	48	89	47	33	18	20
Zn	89	106	99	110	89	122	104
Rb	17	6	2	4	3	8	
Ba	336	93	72	85	50	63	42
Sr	337	343	212	193	236	324	251
Ga	13	16	17	18	18	22	19
Nb	3.2	11.2	4.2	1.4	4.4	13.7	4.5
Zr	63	165	143	79	121	201	145
Y	27	43	37	35	33	76	35
Th			0.35	0.25	0.48		0.53
La			4.32		7.58		8.40
Ce			13.17		20.11		22.76
Pr					0.00		
Nd			12.43		16.01		15.89
Sm			4.95		4.95		5.42
Eu			1.79		1.90		1.92
Gd			6.21		6.11		6.38
Tb					0.00		
Dy			7.16		5.79		6.27
Ho							
Er			4.74		3.16		3.94
Tm							
Yb			4.95		3.26		3.94
Lu							

Table 2-3. Continued

Sample	1542279	1542281	1542314	1542315	1542316	1542073	1542074	1542202
Field No.	BK-83-362	BK-83-364	BK-83-496	BK-83-497	BK-83-509	BK-82-072	BK-82-073	DE-83-057A
Rock Type	lava	diabase	lava	lava	lava	feldspar porphyry	agglomerate	lava
GROUP	CUTWELL	CUTWELL	CUTWELL	CUTWELL	CUTWELL	WAG *	WAG	WAG
SiO_2	49.18	48.16	48.16	48.43	50.47	65.13	58.79	51.42
TiO_2	1.51	1.09	1.82	2.08	1.99	0.65	0.76	2.64
Al_2O_3	16.28	19.84	17.17	15.02	15.79	15.01	15.37	13.94
FeO*	10.09	8.12	11.11	12.96	11.71	6.98	8.22	14.37
MnO	0.20	0.13	0.19	0.23	0.21	0.15	0.12	0.25
MgO	7.15	7.31	5.82	7.19	7.16	1.52	3.79	5.26
CaO	12.40	12.14	11.85	10.07	7.58	4.69	9.07	8.80
Na_2O	2.91	2.93	3.33	3.63	4.86	4.13	2.51	2.74
K_2O	0.15	0.18	0.37	0.18	0.04	1.53	1.27	0.11
P_2O_5	0.13	0.09	0.19	0.22	0.19	0.20	0.09	0.49
LOI	2.35	2.74	2.39	2.69	3.53	4.81	3.29	2.88
Cr	200	246	141	98	45	5	56	
Ni	41	64	36	34	14	1	18	18
V	285	203	350	435	367	101	361	2257
Cu	74	66	65	65	37	39	53	29
Zn	82	60	89	114	132	87	77	141
Rb	3	2	8	3		31	28	1
Ba	59	44	123	70	42	444	303	63
Sr	224	367	323	252	136	197	333	231
Ga	18	17	21	18	16	15	12	22
Nb	4.1	5.1	5.8	8.3	5.0	4.3	3.1	8.3
Zr	87	73	112	133	135	102	32	161
Y	32	31	28	30	33	38	20	46
Th			0.73	0.78	0.48			1.32
La			8.83	11.41	8.36			20.36
Ce			21.70	26.98	21.03			47.55
Pr								
Nd			16.16	18.88	17.18			30.71
Sm			4.47	5.44	5.29			8.63
Eu			1.80	2.14	1.87			1.92
Gd			5.53	5.87	5.83			8.85
Tb								
Dy			5.00	5.44	5.73			8.63
Ho								
Er			3.19	3.41	3.53			4.80
Tm								
Yb			2.66	2.77	3.09			4.90
Lu								

* WESTERN ARM GROUP

Table 2-3. Concluded

Sample	1543339	1543341	1543342	1543343	1543364	1542288	1542312
Field No.	BK-88-014	BK-88-015	BK-88-016	BK-88-017	BK-88-036	DE-83-286	DE-83-507
Rock Type	lava	lava	feldsparphyric dyke	agglom	dyke	lava	lava
GROUP	WAG	WAG	WAG	WAG	WAG(?)	CATCHERS POND	CATCHERS POND
SiO_2	52.51	50.66	55.97	83.74	59.33	48.45	49.67
TiO_2	1.85	1.70	0.64	0.12	0.36	1.75	2.02
Al_2O_3	13.70	14.89	19.01	8.36	14.66	16.85	14.49
FeO*	11.84	11.54	7.81	2.63	5.58	10.28	12.44
MnO	0.20	0.19	0.17	0.04	0.17	0.16	0.19
MgO	5.88	7.67	3.58	0.48	8.03	6.24	6.84
CaO	9.42	10.15	6.20	0.55	8.08	13.01	9.70
Na_2O	3.76	2.27	3.17	4.02	1.75	2.89	4.36
K_2O	0.61	0.67	3.28	0.04	1.87	0.21	0.14
P_2O_5	0.23	0.25	0.17	0.02	0.18	0.15	0.16
LOI	1.28	2.53	3.99	0.83	9.52	2.52	5.54
Cr	79	17			508	226	220
Ni	19	57			190	76	39
V	370	316	207	3	175	264	357
Cu	36	60	40			91	99
Zn	80	72	65	37	62	75	118
Rb	8	12	55		55	2	2
Ba	54	28	936		161	48	64
Sr	220	226	166	23	157	298	148
Ga	20	19	15	6	18	18	16
Nb	8.5	8.0	1.4		6.5	4.3	4.5
Zr	158	126	58	80	76	110	131
Y	35	26	18	27	15	4	32
Th	1.49	0.66	2.67	1.32	2.80	0.32	0.30
La	11.48	8.85	11.00	3.18	14.65		
Ce	27.18	22.12	21.34	9.80	30.87		
Pr	3.91	3.19	2.83	1.43	3.93		
Nd	18.22	14.52	11.76	6.67	16.48		
Sm	5.06	4.06	2.92	2.36	3.31		
Eu	1.78	1.52	0.89	0.61	0.79		
Gd	5.38	4.33	2.57	2.82	2.84		
Tb	1.06	0.79	0.48	0.61	0.48		
Dy	6.66	4.99	3.20	4.32	3.01		
Ho	1.42	1.02	0.69	1.03	0.59		
Er	4.33	2.81	1.92	3.00	1.77		
Tm	0.59	0.39	0.33	0.48	0.27		
Yb	3.64	2.49	2.01	3.30	1.78		
Lu	0.55	0.37	0.31	0.53	0.25		

Table 2-4. COOPER'S COVE AND COLCHESTER PLUTONS

Sample Field No. Rock Type PLUTON	1542203 DE-83-117A gabbro COOPER'S	1542226 DE-83-250 granodiorite COOPER'S	1542227 DE-83-251 tonalite COOPER'S	1542228 DE-83-252 quartz diorite COOPER'S	1542229 DE-83-253 tonalite COOPER'S	1542231 DE-83-254 diorite COOPER'S	1542232 DE-83-255A diorite COOPER'S
SiO_2	54.81	63.45	61.56	56.96	57.89	59.11	58.52
TiO_2	0.17	0.58	0.28	0.23	0.20	0.15	0.20
Al_2O_3	9.17	15.15	15.24	15.31	14.14	12.21	14.25
FeO*	8.40	5.69	7.78	9.32	8.74	9.36	7.39
MnO	0.16	0.12	0.10	0.13	0.15	0.16	0.15
MgO	18.71	3.15	3.79	5.21	7.39	8.69	6.73
CaO	7.35	5.60	9.04	8.45	10.17	9.72	8.61
Na_2O	0.45	2.48	1.77	4.20	1.16	0.52	4.00
K_2O	0.77	3.61	0.39	0.13	0.12	0.05	0.13
P_2O_5	0.01	0.17	0.05	0.04	0.03	0.02	0.01
LOI	3.99	1.50	1.90	1.10	1.50	1.84	0.93
Cr	1485	43	39	48	236	506	134
Ni	409	9	23	28	68	109	49
V	212	164	421	327	295	325	277
Cu	25	17	4	5	3	13	91
Zn	57	57	20	23	36	44	62
Rb	35	112	10		1	7	7
Ba	269	1816	61	31	36	29	46
Sr	38	474	189	145	73	72	115
Ga	6	16	12	10	11	12	11
Nb	3.2	8.2		4.1	1.0	2.1	
Zr	20	100	27	12	7	6	7
Y		13	6	7	8	3	8
Th		11.44	0.90	0.58	0.59		
La					2.58		
Ce					4.14		
Pr							
Nd					2.07		
Sm					0.62		
Eu							
Gd					0.80		
Tb							
Dy					0.57		
Ho							
Er					0.53		
Tm							
Yb					0.46		
Lu							

Table 2-4. Concluded

Sample Field No. Rock Type PLUTON	1542233 DE-83-255B tonalite COOPER'S	1542234 DE-83-255C gabbro COOPER'S	1542271 BK-83-275 quartz-gabbro COOPER'S	1542272 BK-83-276 gabbro COOPER'S	1542275 BK-83-300 gabbro COLCHESTER	1542311 DE-83-487 tonalite COLCHESTER	1543324 BK-88-001 tonalite COLCHESTER
SiO_2	59.20	56.17	54.87	56.32	57.42	69.86	78.40
TiO_2	0.88	0.15	0.19	0.19	0.12	0.19	0.10
Al_2O_3	16.65	10.66	17.27	13.80	9.50	13.91	12.30
FeO*	8.16	9.23	6.72	8.31	8.30	4.86	2.52
MnO	0.15	0.17	0.11	0.15	0.17	0.08	0.02
MgO	3.21	14.15	7.47	10.10	13.95	2.20	0.98
CaO	8.02	8.08	10.97	9.43	8.86	5.01	1.54
Na_2O	3.30	1.25	1.78	1.60	1.34	3.20	4.96
K_2O	0.29	0.11	0.59	0.07	0.22	0.64	0.45
P_2O_5	0.12	0.02	0.02	0.02	0.11	0.03	0.04
LOI	1.93	3.02	1.58	0.97	3.06	1.88	1.23
Cr	32	1117	214	532	919	52	
Ni	6	293	96	146	183	15	
V	201	221	253	267	200	164	22
Cu	91	113	19	4	25	210	
Zn	79	92	28	27	64	50	
Rb	10	1	14		4	11	3
Ba	134	50	125	39	43	148	53
Sr	228	42	136	69	68	109	115
Ga	17	7	15	12	7	12	12
Nb	4.1	2.1	1.1	2.2		4.1	3.6
Zr	146	5	21	26	4	59	91
Y	37	6	4	4		5	9
Th			0.64	0.69	0.80	3.31	4.20
La			2.78	2.65	1.50	7.85	8.64
Ce			5.26	4.26	2.34	15.80	17.64
Pr							1.97
Nd			2.58	2.14	1.18	6.18	7.23
Sm			0.64	0.92		1.36	1.55
Eu			0.57	0.45	0.22	0.64	0.43
Gd			0.64	0.85	0.42	1.21	1.19
Tb							0.21
Dy			0.78	0.62	0.26	0.84	1.42
Ho							
Er			0.44	0.62	0.29	0.84	0.91
Tm							1.22
Yb				0.53	0.22	0.56	0.19
Lu				0.21			

Table 2-5. GEOCHEMISTRY OF INTRUSIVE ROCKS (MOSTLY FINE-GRAINED MAFIC) THAT HAVE NOT BEEN ASSIGNED TO ANY GROUP

Sample Field No. Rock Type	1542009 BK-82-11 gabbro	1542057 BK-82-053A porphyritic diabase	1542058 BK-82-054 diabase	1542062 BK-82-061A feldspar porphyry	1542063 BK-82-061B feldspar porphyry	1542064 BK-82-062A amphibole prophyry	1542065 BK-82-063A andesite dyke
SiO_2	47.14	51.40	51.08	68.94	68.41	49.22	56.46
TiO_2	1.20	0.86	0.83	0.51	0.52	0.84	0.73
Al_2O_3	19.82	16.4	20.03	15.74	16.48	18.51	15.42
FeO*	8.68	11.36	10.07	2.45	2.62	10.59	11.24
MnO	0.16	0.21	0.19	0.06	0.06	0.19	0.20
MgO	7.78	6.68	3.89	1.58	1.86	6.99	4.29
CaO	12.01	10.26	9.23	3.64	2.56	10.50	6.92
Na_2O	2.34	1.31	2.20	4.69	4.76	2.01	2.93
K_2O	0.75	1.26	2.28	2.23	2.58	1.12	1.67
P_2O_5	0.11	0.20	0.20	0.15	0.16	0.05	0.14
LOI	2.89	3.56	2.93	4.31	3.37	3.13	2.67
Cr	177	128	20	24	25	90	5
Ni	62	37	15	19	21	33	15
V	231	370	352	68	67	406	551
Cu	77	125	138	21	16	32	165
Zn	70	98	89	44	49	119	97
Rb	14	23	61	66	69	25	29
Ba	244	474	646	238	701	174	528
Sr	313	227	274	262	299	218	274
Ga	15	14	16	16	17	17	10
Nb	5.1	2.1	5.2	2.1	2.1	2.1	2.1
Zr	70	51	50	105	106	33	49
Y	24	22	23	10	9	19	23
Th							
La							
Ce							
Pr							
Nd							
Sm							
Eu							
Gd							
Tb							
Dy							
Ho							
Er							
Tm							
Yb							
Lu							

Table 2-5. Continued

Sample Field No. Rock Type	1542066 BK-82-66A granite	1542072 BK-82-70 gabbro	1542075 BK-82-74 gabbro	1542076 BK-82-075B feldspar porphyry	1542077 BK-82-76 gabbro (porphyry)	1542079 BK-82-079A feldspar porphyry	1542088 BK-82-097 diabase
SiO_2	70.19	53.63	50.64	53.94	49.11	55.51	47.48
TiO_2	0.34	0.57	1.23	0.54	1.41	0.61	2.60
Al_2O_3	15.90	15.01	17.00	17.91	17.64	18.95	16.37
FeO*	2.04	9.47	9.91	9.17	10.63	8.63	13.24
MnO	0.05	0.19	0.19	0.17	0.21	0.16	0.19
MgO	1.28	8.49	5.86	4.67	6.35	3.45	6.75
CaO	3.16	9.23	10.35	9.16	11.96	8.74	9.06
Na_2O	4.53	2.34	4.12	1.76	2.30	2.83	3.45
K_2O	2.40	1.00	0.51	2.59	0.27	0.99	0.27
P_2O_5	0.12	0.08	0.18	0.09	0.12	0.12	0.58
LOI	5.34	3.91	2.40	4.64	2.66	3.36	3.96
Cr	5	268	17	30	112	16	83
Ni	7	68	14	11	27	16	34
V	454	318	245	303	292	303	422
Cu	10	100	42	66	87	161	67
Zn	40	79	74	87	84	82	106
Rb	58	18	9	49	5	20	2
Ba	211	321	200	271	90	304	161
Sr	292	220	387	225	200	329	253
Ga	18	9	7	16	17	16	22
Nb	2.1	1.0	7.3	2.1	3.1	1.0	14.7
Zr	97	36	88	34	93	45	149
Y	5	19	23	19	38	21	41
Th							
La							
Ce							
Pr							
Nd							
Sm							
Eu							
Gd							
Tb							
Dy							
Ho							
Er							
Tm							
Yb							
Lu							

Table 2-5. Continued

Sample Field No. Rock Type	1542091 BK-82-098B diabase	1542092 BK-82-098D diabase	1542101 BK-82-075A diabase	1542107 BK-82-118B diabase	1542131 BK-82-168 feldspar porphyry	1542137 BK-82-179 diabase	1542138 BK-82-182 diabase	1542201 DE-83-007 feldspar porphyry	1542212 DE-83-173 granite
SiO_2	48.93	53.23	52.72	48.31	65.59	49.33	54.46	62.69	73.29
TiO_2	2.56	1.16	0.53	1.09	0.34	2.12	0.80	0.59	0.17
Al_2O_3	14.66	15.36	13.92	20.46	17.79	15.37	18.97	15.67	15.50
FeO*	14.34	11.97	10.42	7.89	4.25	12.21	8.94	4.42	0.95
MnO	0.24	0.20	0.21	0.14	0.15	0.26	0.29	0.08	0.02
MgO	5.42	5.76	10.09	6.53	1.33	6.23	3.97	5.07	0.68
CaO	10.63	8.72	9.50	12.41	5.30	10.94	8.17	5.64	1.68
Na_2O	2.53	3.48	1.36	2.40	3.85	2.91	3.12	4.54	6.79
K_2O	0.29	0.07	1.20	0.66	1.28	0.45	1.29	1.14	0.86
P_2O_5	0.40	0.07	0.06	0.09	0.11	0.20	0.08	0.17	0.05
LOI	2.47	1.38	3.50	2.67	2.57	2.13	1.70	3.96	1.49
Cr	41	36	323	211	5	78	5	227	12
Ni	22	22	80	64	1	31	5	90	5
V	548	414	313	198	33	317	287	3703	153
Cu	46				7				10
Zn	111	28	110	70	81	86	31	5	19
Rb	5	2	34	11	21	9	32	22	18
Ba	108	65	188	315	237	122	238	255	217
Sr	136	72	143	300	307	224	237	377	389
Ga	17	19	16	17	16	15	15	18	17
Nb	10.3	2.1	4.2	6.2	0.5	6.2	2.1	8.4	4.1
Zr	121	49	34	80	59	152	54	993	77
Y	41	31	17	23	15	47	25	22	
Th					1.93				
La					9.12				
Ce					21.00				
Pr					2.46				
Nd					10.45				
Sm					2.40				
Eu					0.80				
Gd					2.53				
Tb					0.40				
Dy					2.53				
Ho					0.56				
Er					1.57				
Tm					0.24				
Yb					1.64				
Lu					0.26				

Table 2-5. Concluded

Sample	1542213	1542238	1542241	1542242	1542259	1542273	1542274	1542282	1542292
Field No.	DE-83-175	DE-83-267	DE-83-274	DE-83-301A	BK-83-122	BK-83-284	BK-83-285B	BK-83-374B	DE-83-340
Rock Type	diabase	gabbro	feldspar porphyry	felsic dyke	feldspar porphyry	gabbro	diabase	gabbro	diabase
SiO_2	57.76	49.77	50.77	74.23	74.16	50.95	51.21	54.03	46.55
TiO_2	0.27	0.55	0.67	0.30	0.30	1.85	2.16	2.68	3.20
Al_2O_3	15.16	17.47	18.37	12.44	14.07	14.86	15.07	13.79	16.04
FeO*	8.49	6.99	10.04	4.75	2.17	11.90	12.66	14.16	13.08
MnO	0.13	0.12	0.18	0.10	0.07	0.23	0.24	0.30	0.21
MgO	7.87	9.53	7.24	1.02	0.54	6.52	5.37	3.12	7.13
CaO	4.96	12.67	9.63	1.63	2.74	10.20	8.24	6.30	9.23
Na_2O	3.87	2.71	2.42	5.18	4.58	3.20	4.70	4.54	3.42
K_2O	1.46	0.16	0.63	0.29	1.31	0.09	0.13	0.52	0.58
P_2O_5	0.03	0.03	0.06	0.06	0.05	0.19	0.23	0.55	0.56
LOI	2.77	3.33	3.81	1.36	1.06	2.53	2.00	1.84	2.95
Cr	139	515	61	8	6	60	44	10	84
Ni	43	90	21	1	1	18	9	1	64
V	395	26	313	14	17	319	358	149	305
Cu	168	89		20	2	21	4	5	51
Zn	117	55	65	63	34	95	32	158	110
Rb	76		10		13	6	15	3	19
Ba	57	35	85	59	356	65	96	172	209
Sr	85	156	266	151	153	164	177	168	317
Ga	11	11	16	11	10	19	20	27	18
Nb	1.8	3.1		3.1	3.1	4.1	9.3	15.6	13.5
Zr	14	4	16	80	112	118	143	305	190
Y	6	12	20	52	32	39	45	107	54
Th	0.62								
La							2.78		
Ce	2.10						5.26		
Pr	4.69								
Nd	0.52						2.58		
Sm	2.18						0.64		
Eu	0.52						0.57		
Gd	0.17						0.64		
Tb	0.62								
Dy	0.11						0.78		
Ho	0.79								
Er	0.20						0.44		
Tm									
Yb									
Lu									

APPENDIX 3

ANALYTICAL STATISTICS

ANALYTICAL METHODS

Sampling Methods

Samples for geochemical analysis were collected in the field with an 8-pound sledge hammer. Approximately 2 kg of rock chips were collected from the fresh interiors of outcrops. Pillow lava samples were taken from pilow interiors; heavily veined, altered or amygdaloidal samples were avoided where possible. In the laboratory, rock samples were reduced to pea-sized fragments in a chipmunk jaw crusher. After homogenization, approximately 200 g of chips were pulverized in a tungsten-carbide swing mill.

Major Elements

Major element analyses were made using wet chemical methods at Memorial University of Newfoundland (MUN) and the Newfoundland Department of Natural Resources. Volatile content was determined as loss-on-ignition (LOI) at 1000°C. Analyses reported have been recalculated volatile-free to a total of 100 percent, with total Fe presented as Fe0*. The magnesium number of 'Mg#' referred to in this study is the molecular proportion 100MgO/(MgO+total Fe as FeO*).

Precision of major-element analyses (Newfoundland Department of Natural Resources)

Oxide	Mean %	St. Dev.	N
SiO_2	50.78	6.16	28
TiO_2	0.81	0.3	28
Al_2O_3	15.16	1.4	28
Fe_2O_3	2.76	0.87	28
FeO	6.66	0.99	28
MnO	0.16	0.04	28
MgO	7.05	1.79	28
Cao	9.92	3.36	28
Na_2O	2.62	1.02	28
K_2O	0.25	0.26	28
P_2O_5	0.07	0.06	28
LOI	3.41	2.04	28

Accuracy of major-element analyses (Newfoundland Department of Natural Resources). (For a discussion of analysis of international standards see Hayes, 1994.)

GS-N (Granite): source-ANRT			
SiO_2	65.8%	66.00%	66.30%
TiO_2	0.68	0.65	0.67
Al_2O_3	14.67	14.70	14.80
Fe_2O_3	1.92	3.70	3.67
FeO	1.65	-	-
MnO	0.056	0.06	0.13
MgO	2.3	2.25	2.25
Cao	2.5	2.44	2.49
Na_2O	3.77	3.76	3.85
K_2O	4.63	4.63	4.67
P_2O_5	0.28	0.28	0.28

Accuracy of major-element analyses *(Continued)*

UB-N (Serpentinite): source-ANRT			
SiO_2	39.43%	39.9%	39.9%
TiO_2	0.11	0.12	0.14
Al_2O_3	2.91	2.96	2.87
Fe_2O_3	5.36	8.44	8.38
FeO	2.68	-	-
MnO	0.12	0.13	0.12
MgO	35.21	37.86	37.36
Cao	1.2	1.18	1.17
Na_2O	0.1	0.13	0.13
K_2O	0.02	0.01	0.01
P_2O_5	0.04	0.01	0.01
DR-N (Diorite): source-ARNT			
SiO_2	52.8%	52.2%	
TiO_2	1.09	1.00	
Al_2O_3	17.52	17.40	
Fe_2O_3	3.70	9.57	
FeO	5.41	-	
MnO	0.22	0.21	
MgO	4.42	4.35	
Cao	7.05	7.07	
Na_2O	2.99	2.97	
K_2O	1.71	1.71	
P_2O_5	0.25	0.23	

Trace Elements

Trace element analyses were done by X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) at Memorial University. Standard X-ray fluorescence analyses for some samples were also done at the Department of Natural Resources. Separate methods were used to determine groups of elements. These groups of elements and the methods used are as follows:

a) Standard XRF (SXRF)-Cr, Ni, V, Ga, Cu, Zn, Pb, Rb, Sr, Y, Th, La, Ce;
b) Linked repeat (RXRF) and trace (TXRF) XRF-Rb, Sr, Y, Zr, Nb and Cr, Ni, Sc, V, Ba;
c) Thin film XRF (TF-XRF)-rare earth elements (REE-La, Ce, Nd, Sm, Eu, Gd, Dy, Er, Yb) and Y;
d) Bismuth-standard addition ICP-MS (SEICP-MS)-Th
e) Modified multi-element ICP-MS (MEICP-MS)-Th, Nb, Y, REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Er, Yb, Lu).

Application of these separate methods was dictated by both geochemical need and instrument development. SXRF was used initially to obtain all the trace element data. Severe limitations in the **detection limit,** plus accuracy and precision, of this method, particularly for Y and Nb, lead to the development of the RXRF procedure. Linked to the development of the RXRF method was a separate method for determination of transition metals and Ba (TXRF). The increased time required for RXRF/TXRF analyses, necessitated selection of a subset of the original samples. At the same time, the decision was also made to obtain REE and Th data by TF-XFR and SEICP-MS, on this subset. Subsequent, the MEICP-MS technique was developed and a small subset of samples were analyses in 1987-88. Based on interpretation of the geochemical data, a further set of samples (1543324 to 1543666) were collected and all samples in this new set were analysed by RXRF/TXRF and MEICP-MS (1988-89).

In compiling the data, care has been taken to ensure that the highest precision and accuracy analyses available are those listed. TF-XRF analyses are identifiable by the REE data, and distinguishable from MEICP-MS by the absence of Pr, Tb and Lu. Samples analysed by TF-XRF will have RXRF?TXRF and SEICP-MS (Th) data. Y data for samples analyzed by TF-XRF was taken from the associated RXRF analysis. All samples with MEICP-MS also have RXRF/TXRF data. Where there was analytical overlap, within the analytical uncertainties, between the MEICP-MS and RXRF data for Y and Nb a weighted average (0.67 * ICP-MS and 0.33 * XRF) was used. If the RXRF Nb and ICP-MS Nb analyses did not overlap, then the ICP-MS analysis has been used. For samples 1542004 and 1542131 Nb data is from RXRF only.

Precision and Accuracy of SXRF (Memorial University of Newfoundland)

ELEMENT	Detection Limit	RSD at 3*DL	Accuracy 3*DL	ELEMENT	Detection Limit	RSD at 3*DL	Accuracy 3*DL
V	6	8	2	Zr	2	3	5
Cr	5	3	5	Nb	3	13	12
Ni	2	13	10	Ba	35	4	10
Cu	3	4	75	La	10	6	40
Zn	9	3	5	Ce	58	8	15
Ga	3	13	8	Pb	12	8	5
Rb	4	4	5	Th	8	12	12
Sr	5	3	4	U	16	n/a	n/a
Y	5	9	18				

DL-detection limit (in ppm) determined as 3 sigma (counting statistics). RSD-relative standard deviation (percent) for 7 international standards analysed >10 times each, where concentration exceeded 3 times the stated detection limit.

Accuracy based on 4 USGS standards (GSP-1, W-1, G-2, and BCR-1). Data used only when concentration level determined was 3 timed the detection limit. (At concentrations between the detection limit and 3 times the detection limit there is a substantial degradation in the levels of accuracy and precision).

A detailed discussion of the procedure, analytical uncertainties and further statistical evaluation of the data is given in Longerich and Veinott (1987).

Precision and Accuracy of RXRF and TXRF (Memorial University of Newfoundland)

ELEMENT		Detection Limit	RSD (%) at 3*DL	Accuracy at 3*DL	ELEMENT		Detection Limit	RSD (%) at 3*DL	Accuracy at 3*DL
RXRF	Rb	1.	2	2	TXRF	Cr	10	4	5
	Sr	1.0	1	2		Ni	10	7	8
	Y	1.0	7	3		Sc	5	10	16
	Zr	0.9	1	2		V	6	6	6
	Nb	1.0	8	10		Ba	30	20	20

DL-detection limits (in ppm) are 3 sigma (counting statistics). RSD-relative standard deviation in percent.
Accuracy is percent difference between accepted and determined.
Accuracy and precision determined on multiple determinations (>20) of USGS standards BCR-1, AGV-1, W-12, G-2 and GSP-1.
Details of these analytical techniques, blind duplicate and precision checks are given in Swinden (1987; Appendix 6).

Precision and Accuracy of ICP-MS (Memorial University of Newfoundland)

ELEMENT	Detection Limit	RSD (%)	Accuracy	ELEMENT	Detection Limit	RSD (%)	Accuracy
Th	0.013	3	-7	Eu	0.009	4	+7
Nb	0.015	7	-4	Gd	0.03	3	+2.3
La	0.01	1.8	-0.8	Dy	0.018	3	+4
Ce	0.009	1.6	-1.2	Tb	0.006	2.7	+1.0
Pr	0.009	1.9	-2.3	Er	0.02	2.6	0
Nd	0.04	2.2	-1.7	Yb	0.02	2.9	-0.5
Sm	0.03	2.9	-4	Lu	0.006	4	-4

Detection limit given as the concentration equivalent to 3 sigma. RSD = relative standard deviation (percent) based on multiple analyses (>50) of the USGS standards AGV-1, BIr-1, DNC-1, BCR-1, BHVO-1, W-1 and W-2.

Accuracy (percent difference) based on USGS standards AGV-1, BCR-1, BHVO-1 and W-1. Note that determination of Th by SEICP-MS is similar to that used in the MEICP-MS. However, the precision of the determinations by SEICP-MS is 6%.

Details of the analytical procedures and analyses given in Jenner *et al.* (1990).

Precision and Accuracy of TF-XRF

Detailed descriptions of the thin-film-XRF REE procedure are given in Robinson *et al.* (1986). Modifications at Memorial to the procedure of Robinson *et al.* (1986) lead to a degradation of the detection limits and precision. Detection limits for La, Sm, Gd Dy, Er and Yb are approximately 0.6 to 1.0 ppm or 2 to 3 times chrondritic abundances. The detection limits for Ce and Nd are also about 0.6 to 1.0 ppm, but these levels correspond to ≈ 1 times chrondritic abundances. The detection limit for Eu is at about 5 times chrondritic abundances. At concentrations less than 3.33 times the detection limits, the TF-XRF REE patterns are semi-quantitative. In general, the shape of the pattern is correct, but detailed interpretation of the pattern with regard to internal relationships and abundance is tentative. For example, the TF-XRF REE patterns for the boninitic rocks allowed definition of the overall group, as confirmed by later ICP-MS analyses. At concentration levels greater than 3.33 times the detection limits, integration of RXRF, SEICP-MS Th, and TF-XRF data is within 10-20% of the values obtained by ICP-MS, for example in the enriched MORB samples of the Western Arm Group.

Precision of trace element analyses (Newfoundland Department of Natural Resources)

Oxide	Mean (ppm)	St. Dev.	N
Cr	131.61	96.55	28
Ni	48.96	32.96	28
V	255.89	83.07	28
Cu	119.25	192.74	28
Zn	75.07	23.63	28
Rb	7.32	6.49	28
Ba	59.11	39.2	28
Sr	122	35.84	28
Ga	12.89	4.12	28
Li	14.18	12.04	28
Zr	49.29	48.04	28
Ti	4849.61	1822.62	28
Y	27.04	12.98	28

Accuracy of trace-elements analyzed by atomic absorption

Element	Avg. (ppm)	Std.	n
MRG-1			
Ni	150.6	4.3	7
Cu	123.4	5.53	7
Pb	1.6	1.4	7
Zn	196.4	5.12	7
Li	9.1	2.03	7
SY-2			
Ni	4.3	0.83	4
Cu	5.5	0.5	4
Pb	77	28.2	4
Zn	257	2.74	4
Li	90.8	1.09	4

Detection limits for trace elements analysed by X-ray fluorescence (Newfoundland Department of Natural Resources)

Element	Detection Limit (ppm)
Ba	20
Cr	10
V	10
Cu	5
Ni	5
Zn	5
Ga	5
Rb	2
Sr	2
Y	10
Zr	10
Nb	5

Accuracy of trace-element analyses by XRF

Element	Avg. (ppm)	Std	n
GD-2			
Nb	9.2	0.98	5
Zr	59.4	6.34	5
Y	21.4	5.43	5
Th	25	5.4	5
La	7.6	3.32	5
Ce	22.4	9.33	5
BS-1			
Nb	5.8	0.74	4
Zr	115.5	4.58	4
Y	29.8	1.94	4
Th	4.8	5.81	4
La	10	2.53	4
Ce	27	9.65	4

Detailed Analysis of Nb Concentrations

For samples with REE analysis by ICP-MS a detailed analysis of Nb concentrations were done because Nb (the most problematic element from an analytical stand-point) and its relationships to Th and La on the primitive mantle extended REE plot are crucial to defining the tectonic environment.

Nb errors (ppm)

SAMPLE #	Mean (ppm)	Error ppm	SAMPLE #	Mean (ppm)	Error ppm
3334	3.5	0.3	3355	1.1	0.3
3325	0.5	0.2	3356	1.4	0.3
3326	0.8	0.3	3357	2.4	0.2
3327	0.8	0.3	3358	2.6	0.3
3328	0.9	0.2	3359	2.5	0.5
3329	0.7	0.1	3361	1.0	0.2
3331	1.2	0.2	3362	4.5	0.5
3332	0.6	0.2	3363	1.1	0.3
3333	0.6	0.2	3364	5.8	0.5
3334	1.2	0.2	3364	5.8	0.5
3335	0.9	0.2	3366	1.0	0.2
3336	0.8	0.3	2004	0.8	0.4
3337	0.8	0.2	2024	0.7	0.2
3338	1.3	0.3	2036	0.6	0.2
3339	8.2	0.3	2046	0.5	0.2
3341	7.6	0.4	2097	0.8	0.2
3342	1.3	0.4	2116	0.5	0.2
3344	3.0	0.5	2118	0.9	0.2
3345	1.0	0.2	2119	0.7	0.7
3346	1.5	0.3	2131	1.0	0.5
3347	0.9	0.2	2151	1.4	1.0
3348	0.6	0.3	2206	1.2	0.2
3349	0.9	0.3	2213	1.7	0.2
3351	1.0	0.3	2237	1.0	0.3
3352	1.3	0.2	2249	0.7	0.3
3353	1.5	0.2	2266	0.8	0.2
3354	0.9	0.3	2267	1.3	0.5

All sample numbers prefaced by 154.

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